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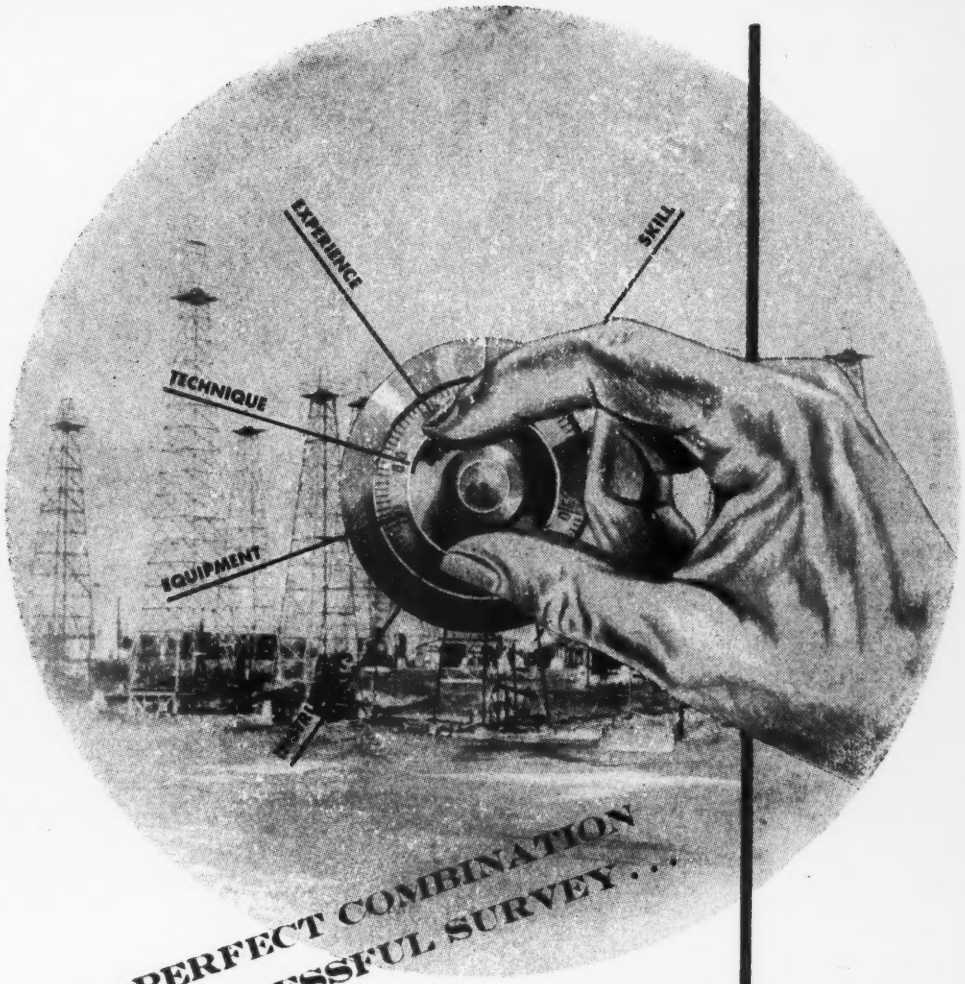

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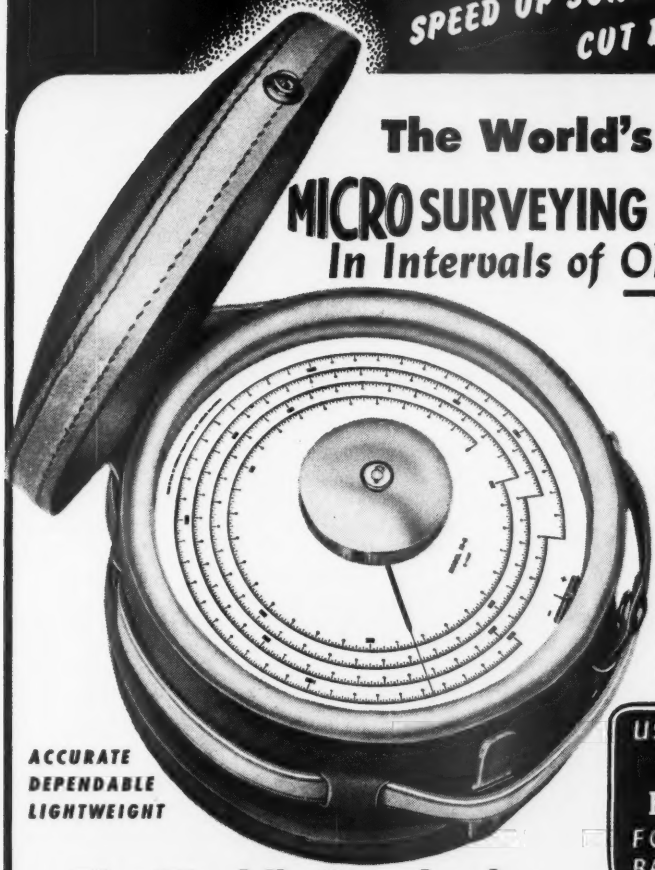

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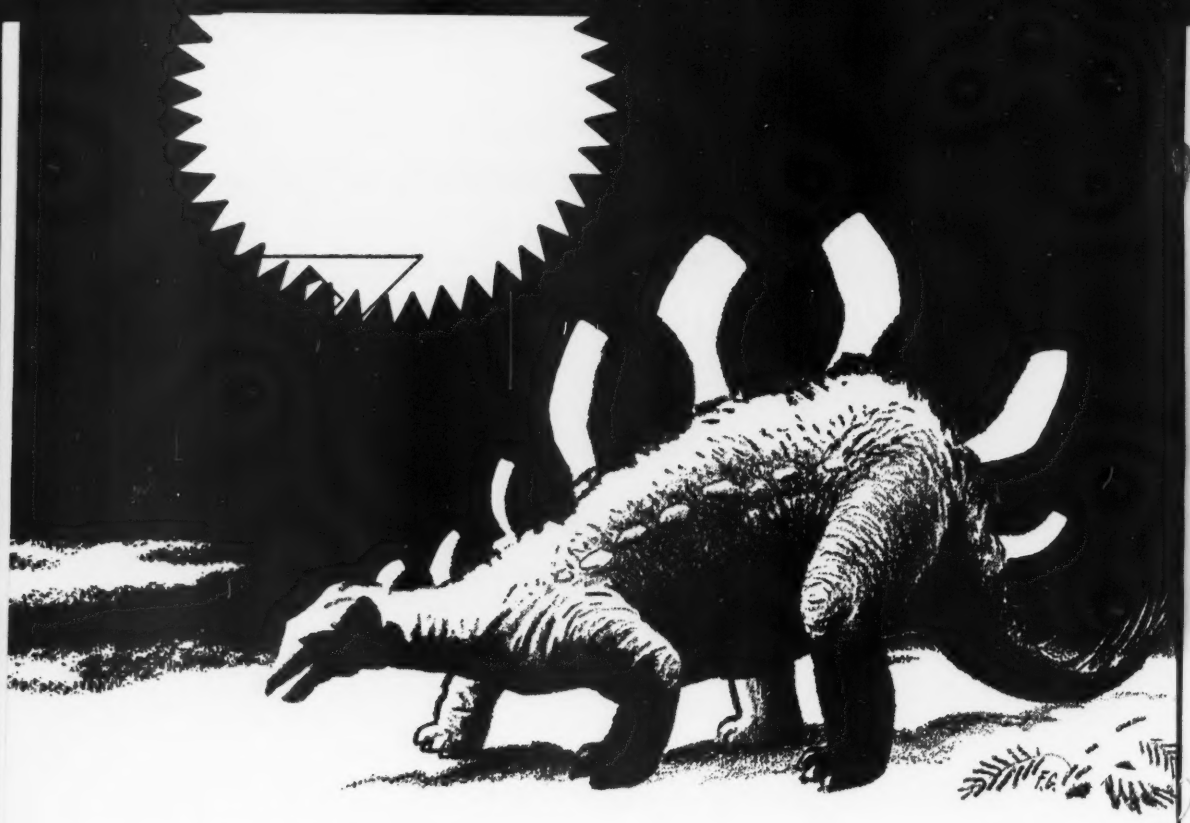

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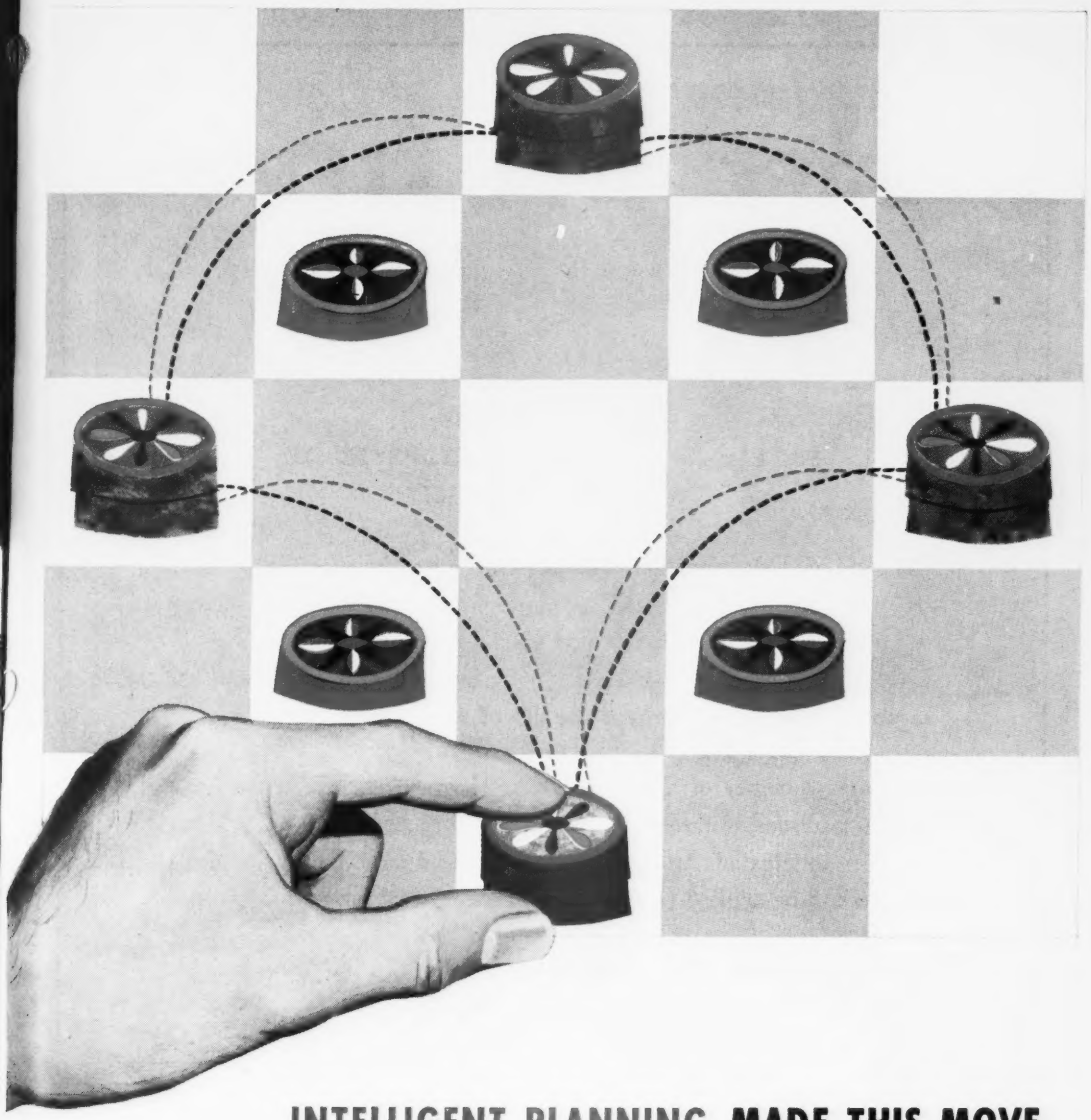

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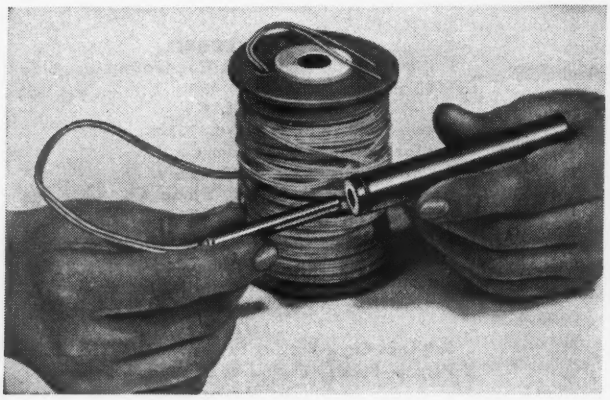

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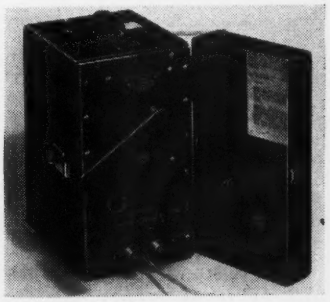

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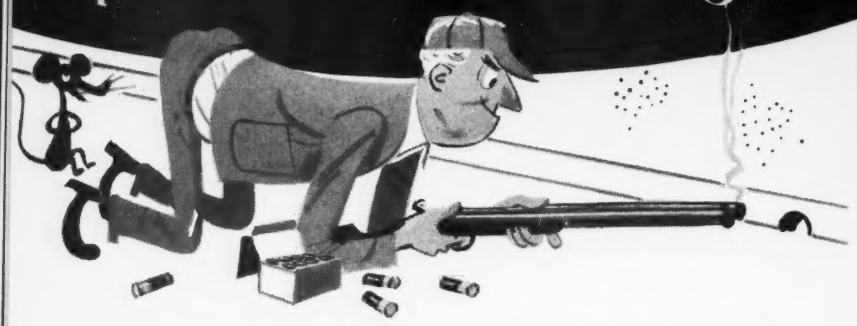

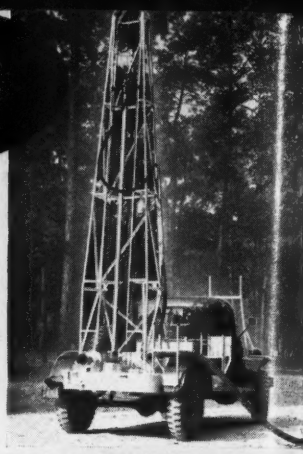

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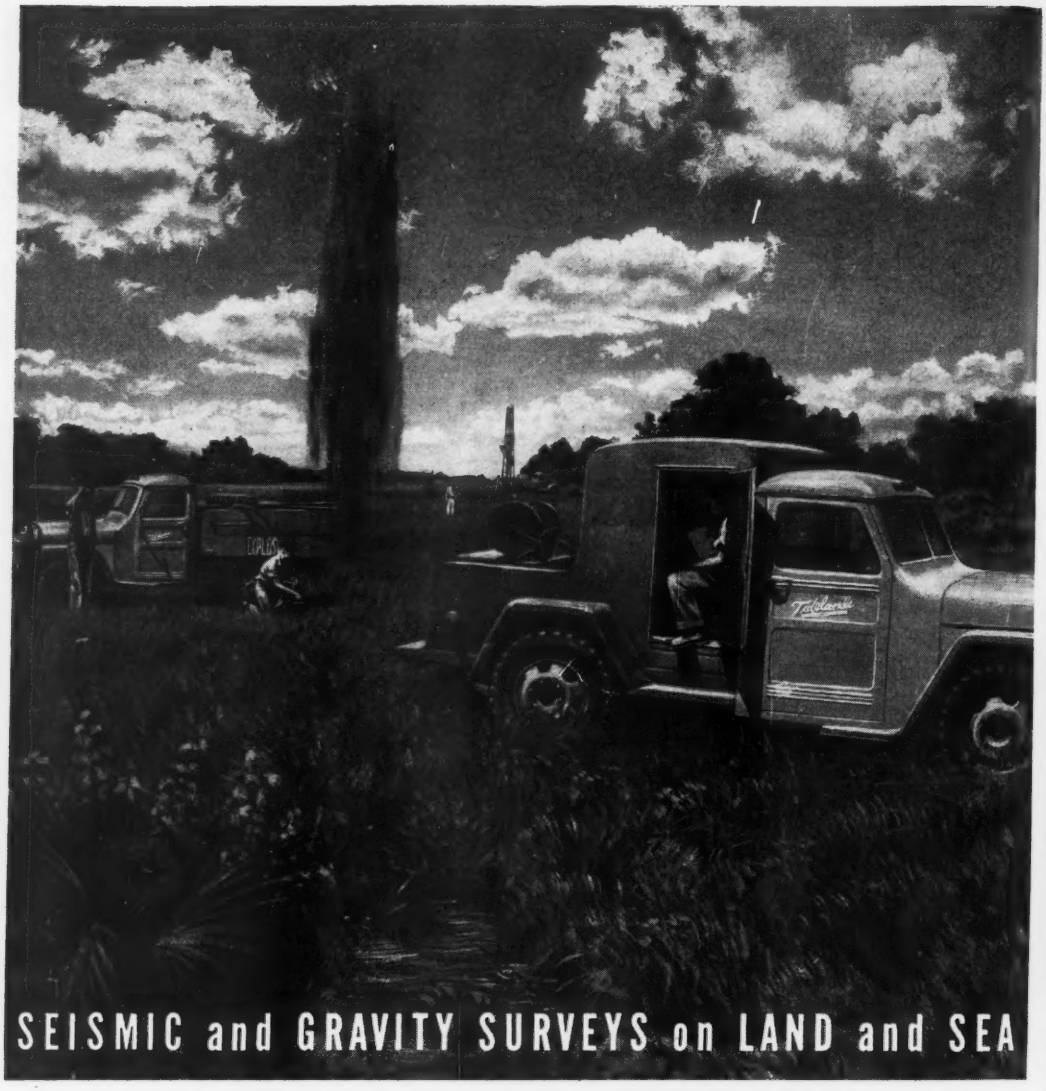

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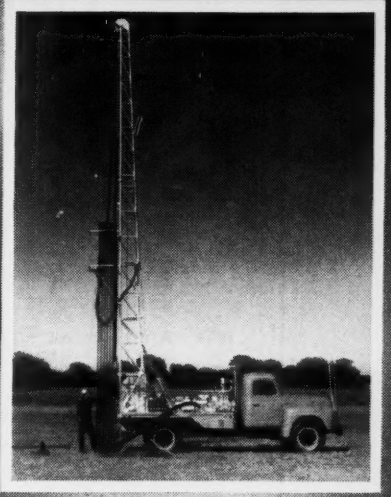

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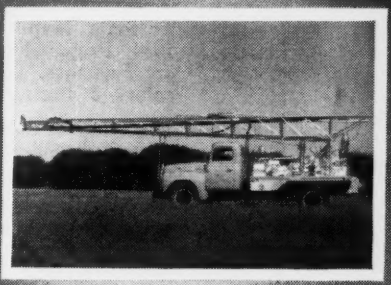

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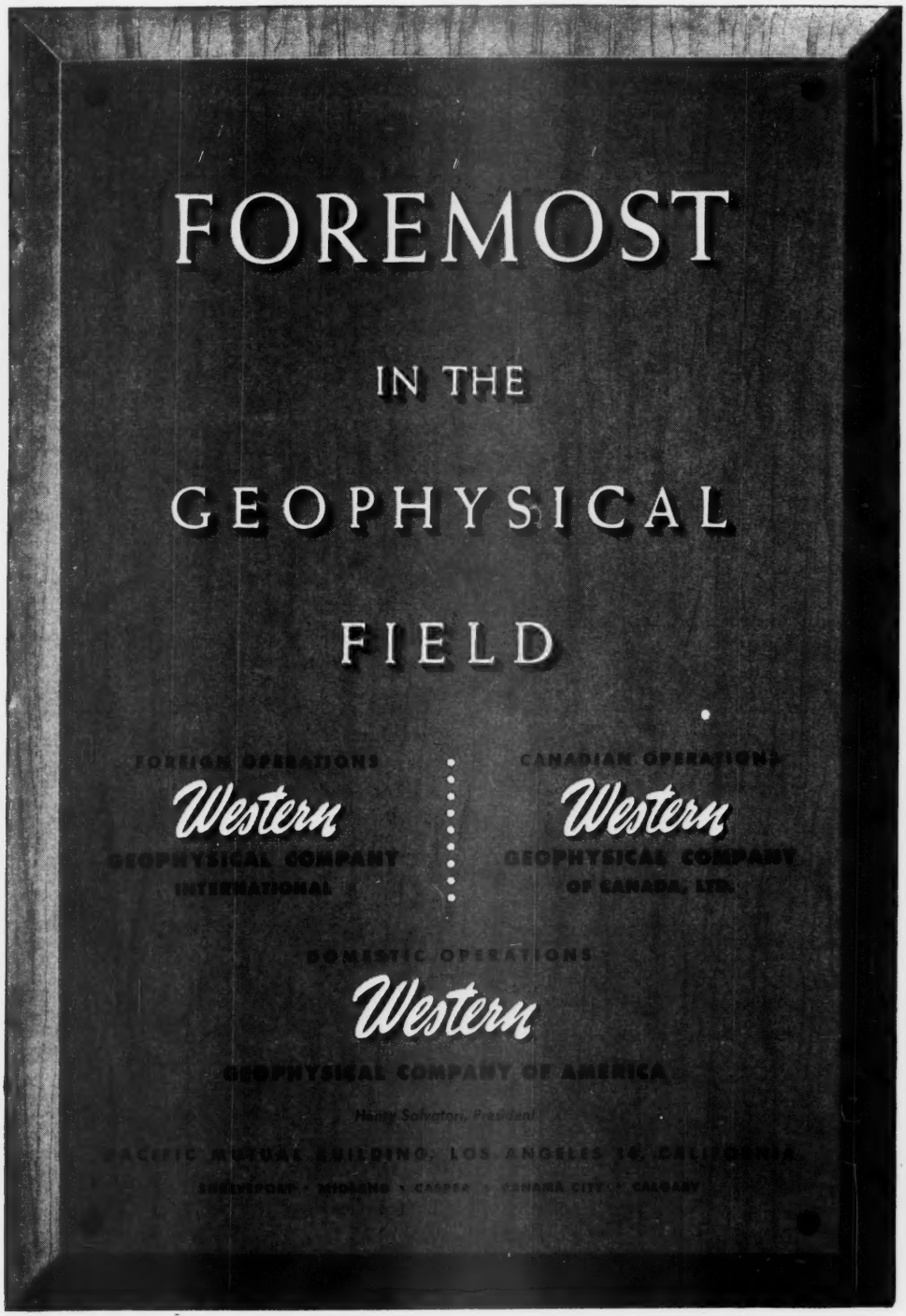

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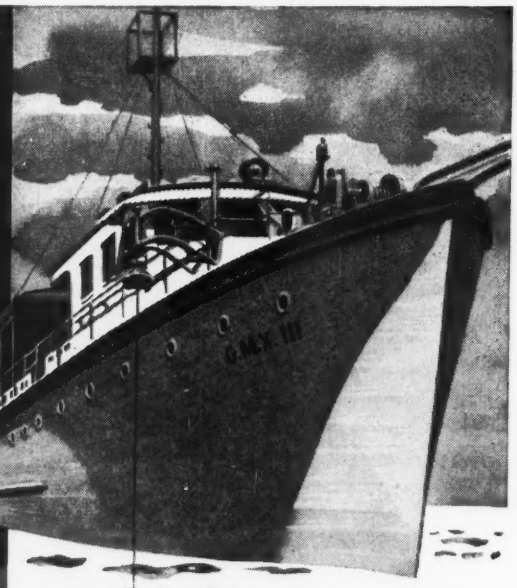

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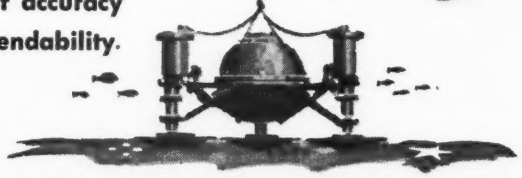

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VOLUME XIX JULY, 1954 NUMBER 3

GEOPHYSICS

PRESIDENTIAL ADDRESS

THE GEOPHYSICIST IN INDUSTRY*

ROY L. LAY†

The key position of the geophysicist on the 1954 exploration team is well recognized by all, but there are perhaps certain phases of his work which have not been fully appreciated. For this reason I propose to discuss in a generalized manner the scope of his present activities.

The geophysicist of today, after more than a quarter century of exploration, is a business man as well as a scientist. His transition from scientist in the 1920's to both scientist and businessman today has not lessened his technical ability, but instead, has qualified him as a better oil-finder. He continues to work with complex mathematical formulae and complicated electronic instruments, and to coordinate his efforts with those of his fellow scientist, the geologist. He applies sound business principles in his exploration work and he must convince his management or client that testing his geophysical prospect is a sound business risk.

As I stated recently in Los Angeles and Dallas, the geophysicist's assignments in petroleum exploration are more challenging today than ever before because he is forced to search for smaller and smaller structures in the more heavily prospected areas, and to devise new techniques in order to obtain results in the problem areas. To meet these challenges, the geophysicist must be well versed in the basic sciences and thoroughly trained in the practical aspects of applied geophysics. In the early days, few of us knew about geophysical prospecting while we were in school, and many of us found employment in geophysics largely by chance or, perhaps, through some associated circumstance, such as the holding of a radio operator's license. Consequently, few of the older geophysicists have had formal training in more than one or two of the sciences basic to geophysics—i.e., geology, physics, mathematics, and electronics. Most of us, schooled in only one field, have had to acquire knowledge in other sciences as we went along. In the past this has worked surprisingly well, yet all of us realize the advantage of attracting into the industry students whose formal education is broad enough to include several of the sciences.

* Presidential Address presented at the Annual Meeting of the Society in St. Louis, Mo., April 13, 1954. Manuscript received by the Editor April 15, 1954.

† Assistant to Vice-President, Producing Department, The Texas Company, New York, N. Y.

The Public Relations Committee of the Society of Exploration Geophysicists has been working on this problem for several years, and I am happy to report that their efforts are now culminated in a comprehensive and beautifully illustrated brochure entitled "Careers in Exploration Geophysics." This booklet is sponsored by industry, and at least one copy will soon be furnished by the SEG business office to every high school and university in the United States. It is our hope that the brochure will tell a much needed story to high school and college students early enough to interest them in planning a career in geophysics. The brochure will be helpful to teachers and parents in advising those students who are properly qualified for scientific careers. These students are the future oil-finders of the industry and from this group will come young men of intelligence and imagination, who in the future will fill the responsible jobs in the exploration industry. Furthermore, SEG is actively promoting interest in geophysics by the formation of new student sections in universities and colleges and by holding student essay contests and presenting an annual award for the best geophysical paper prepared by an undergraduate.

I do not belittle the great value of highly trained specialists, both in geophysical research and in exploration, but such specialization results in restricted assignments. Industry needs more men who have the advantage of broader training, especially with the advent of magnetic recording and electronic computing—both of which will have many new applications yet undreamed of.

As a scientist the geophysicist must be trained practically as well as academically. He must know the limitations of geophysical methods as well as their applications. And he should always bear in mind that his scientific data must be of practical use to his fellow scientist—the geologist. Industry has found it both necessary and profitable to establish and conduct its own training courses to further this end. As an example, several companies have effective programs to give their geophysicists and geologists a working knowledge of each other's methods and problems. Such training courses are not intended to make expert geophysicists out of geologists, or vice versa, but rather to broaden the training of each, and to effect a better and more sympathetic understanding of their mutual problems. Perhaps equally as important is that, through these courses, geologists and geophysicists get to know each other personally, furthering their cooperation.

The avenues for a coordinated scientific approach are very broad and there should always be a complete interchange of ideas. The geologist can often help the geophysicist analyze near-surface variations by furnishing information directly associated with lateral variations in velocity due to stratigraphic changes. Geologic cross-sections based on subsurface information can often be of great assistance to the geophysicist, and will usually result in an improved interpretation rather than one which may be doubtful. Patience and persistence are required because the interpretation of geophysical data in terms of geologic structure is frequently neither straightforward nor easy.

The geophysicist should have an open, inquisitive mind, and imagination tempered with good judgment. I think you will agree that the best interpreters are

those who do not have preconceived ideas and who are not reluctant to change. We must never assume, once a traverse has been closed and the interpretation made, that the basic data can be filed away and forgotten. Such a "once over lightly" treatment of scientific data, current or otherwise, is a serious mistake. Too often, an interpreter is inclined to pick a group of seismic records, tie the data into existing subsurface control and rest complacent, believing he has made a good interpretation. Such an interpretation, perhaps, may be sufficient for present requirements, but the interpreter should ask himself: "Is there any information remaining on these records, or is there a conflict that additional data may resolve?" The answer is, almost invariably "yes," and the interpreter who says "no" is deceiving himself. To do justice to these scientific data we must be conscientious and thorough in making our interpretations.

The geophysicist should never lead others to believe that the data are exact, but he should acquaint them with the limitations before a test well is drilled. Such procedure will obviate the belief that the data are worthless if the well fails to check the geophysical interpretation. Instead, it should be realized that more nearly accurate geophysical interpretations result as additional information is obtained, and that a review of the basic geophysical data in the light of new development is highly desirable and in many cases imperative.

The other important role of today's geophysicist is that of being a good businessman. The primary objective of any business is to make a profit; in exploration work the geophysicist makes a profit for his employer by finding favorable prospects at the lowest possible cost. Industry is spending approximately two hundred million dollars annually for geophysical work in the United States and Canada. The major exploration effort represented by this tremendous expenditure demands wise, efficient administration.

The matter of conducting geophysical work effectively and efficiently is geophysical management's responsibility. Management must provide and maintain a high-class organization in correct balance to obtain the desired objective. Experienced field parties must be supported by an adequate and well-trained supervisory staff to plan and review progress of the field work, to check the quality of the data obtained, and to assist in solving interpretational and operational problems. An active and well-directed research program is essential for the development of new techniques and instruments.

Geophysical management has a firm obligation to assist in planning an intelligent exploration program. Estimates of the cost and of the probable quality of the geophysical data to be obtained are very important factors which must always be considered. In certain areas, information regarding the use of new techniques may give the company or client a temporary advantage over competitors. Once the program has been approved it is up to geophysical management to see that the work is carried on in the best possible manner, both technically and operationally.

As a businessman the geophysicist in management must see that proper effort is directed toward the review of old data. It is no secret that many of us have maps which, in the light of present day requirements, are completely inadequate.

A contoured interpretation, whether it be geophysical or geological, tends to give us a feeling of security: we are too often content in the belief that our coverage is adequate, and our interpretation reasonably accurate. It is my firm belief that a review staff can make substantial contributions, not only by discovering new prospects and effecting considerable savings in lease rentals, but also by pointing out these potential danger areas where the complacent use of inadequate data may allow competitive companies an advantage. Early reconnaissance-type surveys effectively revealed the large structures, but today, in our search for fault traps and structures buried at depths of 10,000 feet or more, the reconnaissance maps from those early surveys do not furnish adequate detail or depth coverage. A review staff can be of considerable assistance in evaluating these old surveys in the light of new information. More and more of this effective and economical type of exploration will be done in the years ahead.

As a businessman, the geophysicist must stress the importance of good public relations. Too little emphasis has been placed on this important program in the past. Modern exploration requires the utmost respect for other people's rights and the geophysicist must educate his employees that good public relations with landowners and local townspeople are essential to successful operations in any area. As R. W. Dudley stated in an article entitled "Public Relations in Geophysical Prospecting",

> "The geophysical prospecting crew is usually the landowners' first contact with the operating phases of the oil industry. The first impression may have a lasting effect for good or ill, on the public relations status of the entire industry."

Some crews are maintaining high standards in public relations and winning warmhearted acceptance of local communities as evidenced by letters of commendation from Chambers of Commerce, ministers, and public officials. Such exemplary conduct on the part of geophysical crews reflects very favorably on an individual company's reputation and that of the entire industry. Let us hope for many more favorable reports of this type.

A definite responsibility of geophysical management is that of organizing and directing an effective safety and accident-prevention program. The humanitarian and economic reasons are so obvious it is not necessary to enumerate them. Great strides have already been made by industry in reducing hazards and prohibiting unsafe practices but, even so, it is a matter of record that much room for improvement remains. The effectiveness of industry's conscientious effort thus far is shown by the remarkable decrease in accident frequency rate from 53.5 in 1951 to 28.1 in 1952 and 18.6 in 1953. This decrease of 65% from 1951 to 1953 resulted in an estimated saving to the industry of more than $750,000 in direct costs and in reduced insurance rates. As good businessmen, geophysicists at every level have an obligation to their co-workers and to their companies to continue to carry out the safety programs conscientiously toward reducing needless suffering and toward saving many more thousands of dollars.

Every businessman is concerned fundamentally with costs and profits. The geophysicist in management should be sure that an adequate cost-accounting

system is maintained to furnish detailed, up-to-date data on all geophysical costs, and he should analyze and compare such data frequently to determine how costs can be reduced and unnecessary expenses eliminated. He must also emphasize that certain items which do not appear directly in the geophysical budget may seriously affect company profits and should be given close attention. For example, in recent years many geophysical expenditures have been treated taxwise as capital investment rather than as necessary business expense. The geophysicist is in a unique position to reduce the resulting extra tax cost by properly governing the size, duration, and timing of geophysical surveys.

The geophysical supervisor, the party chief, and other key employees must likewise be good businessmen. Obviously, their first and most important duty is that of securing good data, properly recorded and interpreted. If the data or interpretation are poor, the company risks spending large sums of money in vain, and more seriously, of losing out altogether in an area of interest. As good businessmen, they must be constantly aware of their duty to obtain these data at optimum cost. Although management controls the general field organization and its operating budget, alert field personnel can effect many cash savings, and upon their judgment depend many variable costs, such as those associated with shot hole depth, charge size, instrument spacing, extra labor and equipment. Week-to-week program planning, with regard to area, weather, and season, can affect costs considerably. A field party may be overstaffed. A crew may continue to shoot several times as much dynamite as necessary simply because some prior shot point was insensitive. Extra items of equipment may be retained temporarily because of possible need "next week" when, in reality, weeks often grow into months and much needless expense is incurred. The geophysicist who is a top-notch businessman will keep his eyes open to ways and means of doing the job better and at less cost.

Last, but not least, the successful geophysicist must be an able salesman throughout his career. He must first sell himself to his fellow workers and to his superiors. Opportunities to sell the products of his work and thought come as he is given increased responsibility. The geophysical map may be accurate and the data may have been obtained at minimum cost, but the geophysicist has not fulfilled his obligations either to his company or to his client unless he presents the results clearly and honestly. His recommendations must be presented with due regard for the scientific and economic factors which have influenced his decisions. Confidence is inspired by a reputation for frank appraisal and a record of dependability. The geophysicist should give all his ideas and recommendations this simple test before presenting them to management: will they contribute to his company's progress and profit?

"The Geophysicist in Industry" has an assignment that is demanding, but one that is fascinating and rewarding. His growth as a scientist is clearly evidenced by the numerous technological advancements over the years. He has developed into a full-fledged businessman and is taking a well-earned place in the management of many companies. The future is bright and he can look forward with confidence.

GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 388–401, 13 FIGS.

TECHNICAL PAPERS

SEISMIC MODEL STUDY OF REFRACTIONS FROM A LAYER OF FINITE THICKNESS*

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ABSTRACT

Two dimensional model experiments on refractions from layers of finite thickness are described. Refractions can be unreliable for velocity and depth determinations when they occur with wavelengths which are large compared to the layer thickness. Discrepancies reported between refraction velocities and borehole velocities can be partially accounted for in this manner. Even simple two- and three-layer models can show such effects as misleading second arrivals, echeloning of travel time curves, masked layers, and selective absorption in the overburden.

INTRODUCTION

It seems obvious that refraction shooting methods will give a proper velocity for a layer only if the wavelengths of arrivals are small compared to the layer thickness. Yet there has apparently been no discussion of this point in the literature despite the fact that refraction arrivals often occur with wavelengths so long as to cast doubt on the validity of usual methods of interpretation. Indeed, experimental investigations usually reveal discrepancies between layer velocities determined by refraction shooting and by measurements on cores or in boreholes. An excessive value of the ratio of wavelength to layer thickness may well contribute to this discrepancy. This paper is a preliminary report on model experiments where the thickness of the refracting layer is varied, while other parameters are held approximately constant. It is planned to discuss some points of the theory of refraction arrivals from a layer of finite thickness in a following paper.

Earlier work on the theory of refraction arrivals (Jeffreys, 1926; Muskat, 1933) was concerned primarily with proving that energy could propagate along the ray paths required by travel time data. Consequently the problem was simplified by considering an infinitely thick refractive layer.

More recently Sato (1952) and Officer (1953) studied the refracted wave at large propagation distances in a two-layer medium, the bottom layer being infinitely thick and having a higher velocity. They showed independently that the

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predominant refraction arrivals occur with certain discrete frequencies determined by the condition for constructive interference of waves multiply reflected at the critical angle within the surface layer. Perhaps the most complete paper on the general subject of refracted and reflected waves in a system consisting of a solid layer overlying a semi-infinite solid bottom is that of Newlands (1952). All of these investigations, however, deal with an infinitely thick refracting layer.

An elementary example may be used to show one mechanism through which wavelength becomes a significant factor when the refracting layer has finite thickness. Considering, for simplicity, a liquid refracting layer of thickness H, sound velocity α, we find that the pulse reflected at almost grazing incidence from the bottom of the layer follows the refracted pulse after an approximate time $2H^2/x\alpha$ where x is the horizontal distance through the layer. For $x \sim 20H$ this corresponds to a time interval of about 1/100 sec when H is 1,000 ft and α is 10,000 ft/sec. Now if the spectrum of the source and absorption in the overburden are such that the refractions have significant components with periods greater than 1/100 sec, interference effects occur and the resultant disturbance may travel with velocity different from α. At large distances compared to the layer thickness the refraction pulse may in this manner be inseparable from pulses multiply reflected near grazing incidence within the layer and the resulting interference pattern will have quite different characteristics from the simple refraction pulse of an infinitely thick layer.

EXPERIMENTAL PROCEDURE

The two dimensional model seismology techniques and equipment described by Oliver, Press, and Ewing (1954) were utilized in this work. Models were easily fabricated from sheets of Plexiglass, brass, and aluminum 1/16 inch thick bonded with Duco cement. Wavelengths long compared to this thickness were used so that the only elastic parameters involved were the plate velocity V_P, the shear velocity β and the density ρ. Except for the substitution of V_P for compressional velocity α, the results are analogous to two dimensional propagation in three dimensional media. The usual method of multiple exposure photography of a cathode ray oscillograph screen was used to simulate a refraction spread.

EXPERIMENTAL RESULTS

Propagation in a Single Layer

Although not of primary concern in this paper, the single layer is an important preliminary. It is necessary to understand the seismograms from this simple case before proceeding to multilayered media.

A single sheet of Plexiglass 6×50 inches serves as a model for a single layer. The source was located 4 inches from a corner and a spread running from 4–42 inches with a detector spacing of 2 inches was utilized. Wave types satisfying the observed travel times are shown in Figure 1. Seismograms are presented in

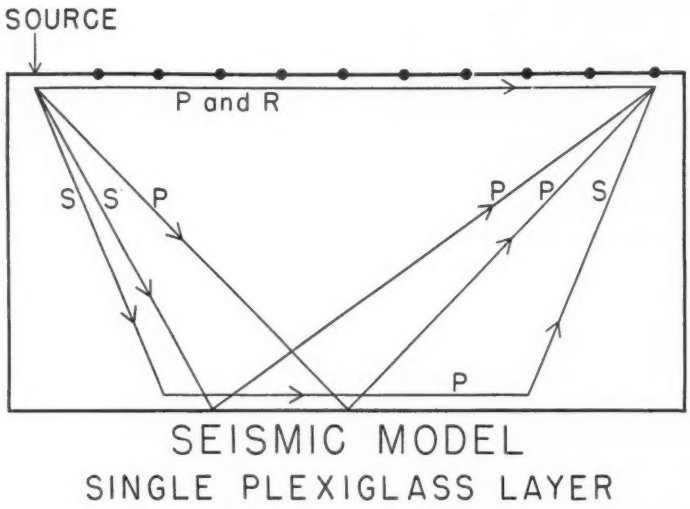

FIG. 1. Types of waves observed in single-layer model.

Figure 2 for the spreads 4–20 inches, 22–38 inches, 28–36 inches, and 36–42 inches. A travel time curve appears in Figure 3.

For waves associated with the upper edge, the single sheet models the problem of propagation in a half space first considered by Lamb (1904). For waves arising from reflection or refraction at the bottom interface the single sheet is somewhat analogous to the problem considered by Lapwood (1949), that of propagation from an internal line source in a semi-infinite elastic medium.

The seismograms and travel time curves show the diffracted P wave propa-

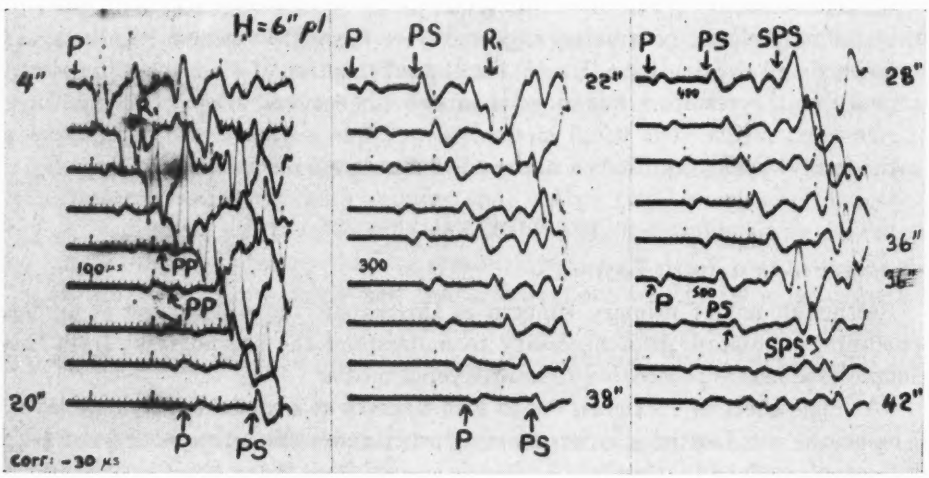

FIG. 2. Seismograms for spreads 4–20 inches, 22–38 inches, 28–36 inches, 36–42 inches on a single layer of Plexiglass, $H=6$ inches. Time marks shown are at 100 and 10 microsecond intervals.

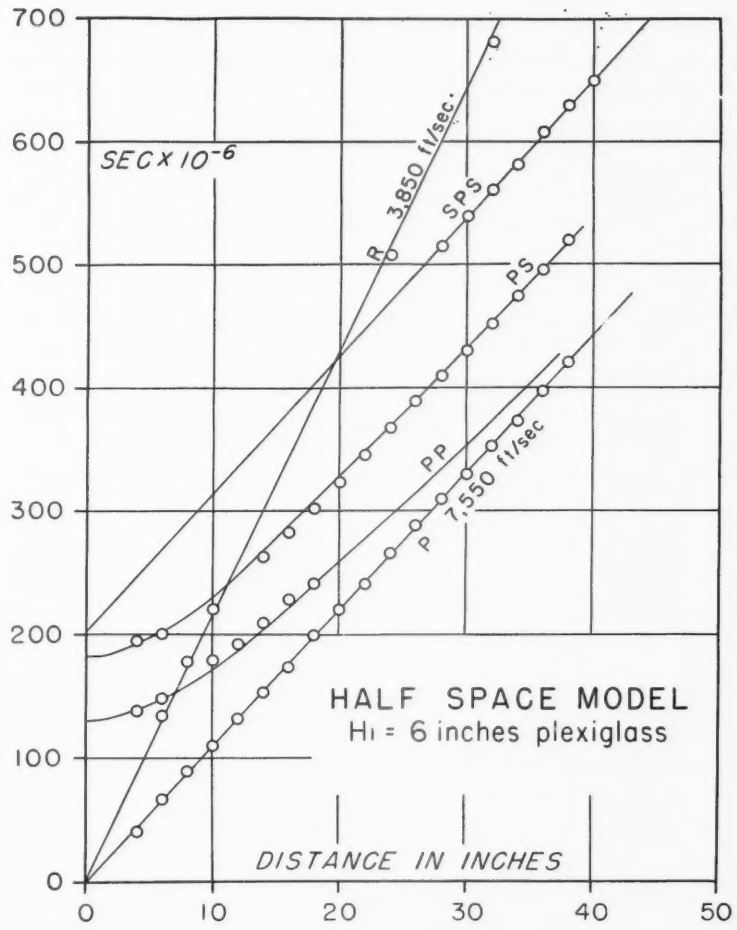

FIG. 3. Travel time curve for a single-layer model.

gating along the top edge to be the first arrival for the entire spread. A velocity of 7,550 ft/sec is indicated for the plate wave in Plexiglass. The first wave to emerge from the surface Rayleigh wave is *PP*. It is seen clearly as a second arrival in the seismogram traces at 12, 14, and 16 inches. For distances greater than 16 inches *PP* begins to interfere with *P*. This merging of *P* and *PP* illustrates the elementary case discussed in the introduction. However, serious alteration of *P* does not occur in this experiment because of poor excitation of grazing *PP* by the source.

A striking feature of the seismograms is the large amplitudes of the phases *PS* (or *SP*) and *SPS*.[1] The latter phase had been theoretically established by

[1] The family of refractions PSPSP has identical travel times to SPS and could not be distinguished from it.

Nakano (1925) and has only recently been experimentally verified. Since *SPS* follows a least time refraction path it can be used to model the refraction arrival in water covered areas discussed by Officer (1953). Here the single sheet would actually represent two liquid layers, an upper layer of finite thickness with sound velocity β and a semi-infinite lower layer having sound velocity α.

Rayleigh waves associated with the upper edge were by far the largest disturbance. As predicted by Lamb they propagate without change in character.

Propagation in Two Layers

In this model the surface layer was a Plexiglass sheet 50×4 inches. The refracting layer consisted of an aluminum sheet 50×$\frac{1}{4}$ inch in one case, and 50×4 inches in another. Refraction spreads were run from 4–36 inches for each case, first on the Plexiglass edge, then on the aluminum edge, with detector spacing of 2 inches.

The waves identified for both cases are shown diagrammatically in Figure 4. The direct wave P_1, the Rayleigh wave R_1, and the refraction arrival $P_1P_2P_1$ were observed for the spread on the Plexiglass edge. The direct wave P_2 and the Rayleigh wave R_2 were observed for the spread on the aluminum edge, as well as the phase $P_2P_1P_1P_2$. This phase was found only for the thin layer, for which case it has the same travel time as $P_1P_2P_1$ and differs from the latter in that it is initiated and detected in the refracting layer. Seismograms for the cases of thick and thin refracting layer are shown in Figures 5 and 6 respectively. In each figure the seismogram for the spread on the Plexiglass edge is on the left and that for the spread on the aluminum edge is on the right. A combined travel time curve appears in Figure 7.

Perhaps the most significant feature of the travel time curve is the lower velocity of P_2 and $P_1P_2P_1$ for the $\frac{1}{4}$ inch aluminum layer. That this was not due to inherent differences in the elastic parameters of the aluminum was verified by cutting the $\frac{1}{4}$ inch strip from the 4 inch aluminum layer along the same edge used to measure P_2. The reduction in velocity from 17,750 ft/sec to 16,950 ft/sec is of the proper magnitude for the difference between V_P and the one dimensional bar wave with $\overline{V}_P \approx 2\beta\sqrt{1-\beta^2/V_P^2}$. It is not surprising that the velocity of P_2 and $P_1P_2P_1$ measured for the $\frac{1}{4}$ inch aluminum layer is $\overline{V}_P$ in view of the large value $\lambda_2/H_2 \sim 8$ for the ratio wavelength λ_2 to thickness H_2. It may be argued that a plate wave cannot exist in a layer loaded on one side by Plexiglass. Apparently such a wave can exist under these circumstances of large contrast between the layers (Press and Ewing, 1951). To insure that the lower velocity was indeed due to propagation of P_2 as a one dimensional bar wave an additional test was made by freeing the $\frac{1}{4}$ inch aluminum strip from the Plexiglass and finding that the velocity of P_2 was unchanged.

This experiment contrasts the refraction arrival and direct wave through a thick and thin layer. The results show clearly that the velocities determined differ significantly for the two cases $\lambda \gtrless H$. The results suggest that the velocity

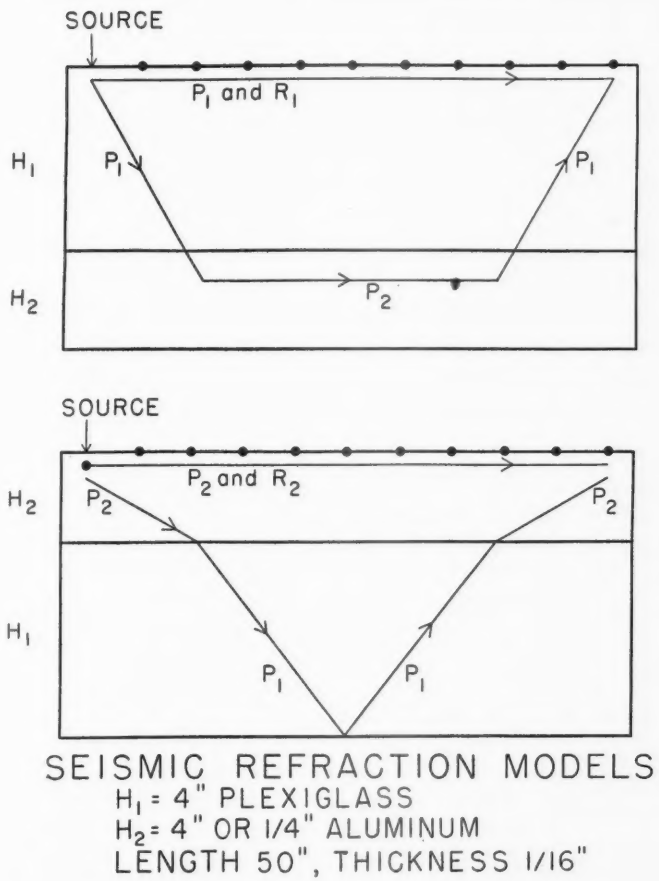

FIG. 4. Types of waves observed in double-layer model.

of the refraction arrival is identical to that of the direct wave through the layer. Some additional conclusions may be reached by inspection of the seismograms in Figures 5 and 6.

In Figure 5 the direct wave P_2 through the thick aluminum layer may be characterized by its content of both low and high frequencies. Apparently a thick layer will support propagation of P_2 over a large (though not necessarily continuous) range of frequencies. In the same figure the refracted wave $P_1P_2P_1$ is characterized by the presence of only the low frequency components of P_2. This is interpreted as an effect of absorption of the high frequency components (>100 kc) in the Plexiglass along the incident and emergent portions of the $P_1P_2P_1$ path.

In Figure 6 the P_2 arrival for the thin aluminum layer contains mostly high frequency ($\sim$100 kc) components. The corresponding wavelength of about 2 inches is large compared to the $\frac{1}{4}$ inch layer thickness, hence P_2 for this case is a

one dimensional bar wave as discussed earlier. The refraction arrival $P_1P_2P_1$, especially at large distances, contrasts markedly with the corresponding arrival for the thick layer. The former is weak and low frequency components are almost absent. These results are interpreted as an indication of poor excitation of low frequency P_2 energy in a thin layer and absorption by the Plexiglass of the predominantly high frequency energy that can be transmitted along the P_2 portion of the refraction path.

The similarity in character of the events $P_2P_1P_1P_2$ and $P_1P_2P_1$ for the thin refracting layer is not surprising since the paths traversed by these phases differ very little. However this similarity, despite the difference in source and detector location for these phases, again suggests that much of the character of the $P_1P_2P_1$ phase is determined by the effects of propagation in the competent P_2 layer and selective absorption of high frequencies in the Plexiglass layer.

Propagation in Three Layers

The three-layer model was fabricated from sheets of Plexiglass, brass, and aluminum 72 inches long. The widths of the layers were as follows:

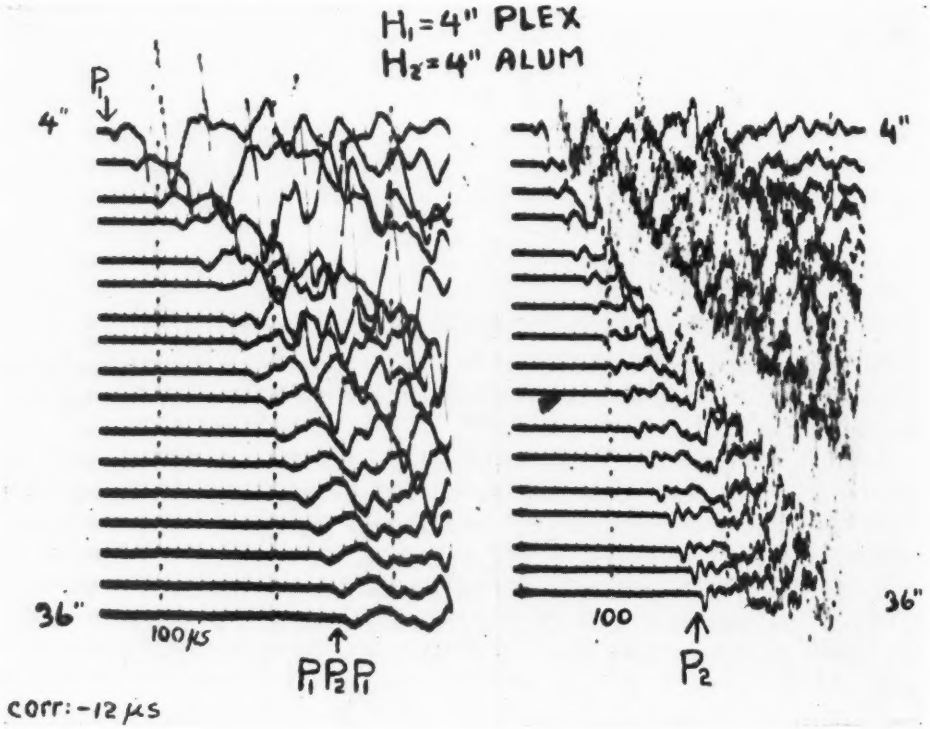

FIG. 5. Seismograms for spreads 4–36 inches on a double layer, $H_1=4$ inches plexiglass, $H_2=4$ inches aluminum. Spread on Plexiglass edge on left, aluminum edge on right.

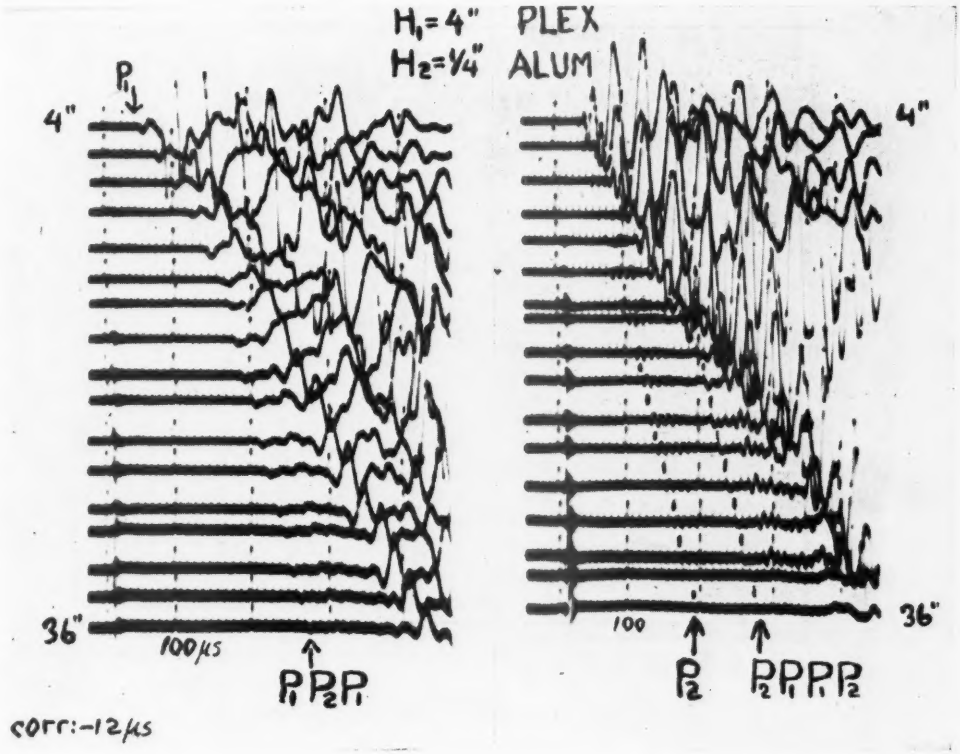

FIG. 6. Seismograms for spreads 4–36 inches on a double layer $H_1=4$ inches Plexiglass, $H_2=\frac{1}{4}$ inch aluminum. Spread on Plexiglass edge on left, aluminum edge on right.

Case I	*Case II*
$H_1=6$ inches Plexiglass	$H_1=6$ inches Plexiglass
$H_2=1\frac{1}{4}$ inches brass	$H_2=6$ inches brass
$H_3=8$ inches aluminum	$H_3=8$ inches aluminum

Refraction spreads were run along the Plexiglass edge from 4–60 inches for Case I and 2–64 inches for Case II, with detector spacing of 2 inches. In Figure 8 the various types of observed waves are depicted. Seismograms for the two cases are shown in Figures 9, 10, 11, 12, and a travel time curve appears in Figure 13.

As shown in the travel time curve and indicated on the seismograms, refractions $P_1P_2P_1$ and $P_1P_3P_1$ were obtained for both cases. For Case I, however, the thin brass layer was masked and $P_1P_2P_1$ could be read only as a second arrival at distances from 12–20 inches. This same phase appears clearly in Case II as a second arrival from 8–24 inches and as a first arrival from 24–38 inches. Examination of the seismograms in Figure 9 shows that $P_1P_2P_1$ has essentially the same pulse-like character for both cases at these small shot-detector distances. With

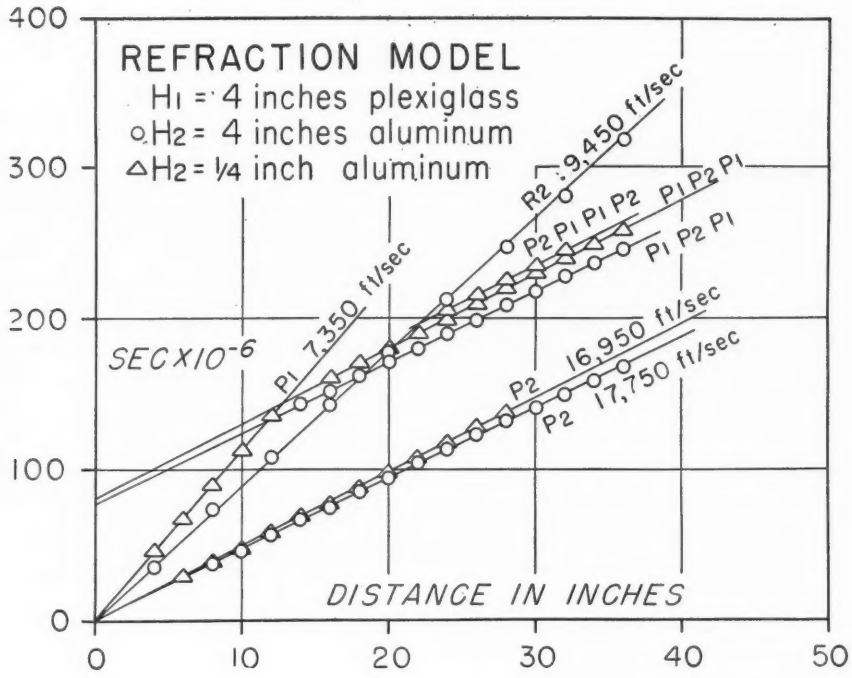

FIG. 7. Travel time curves for double-layer model.

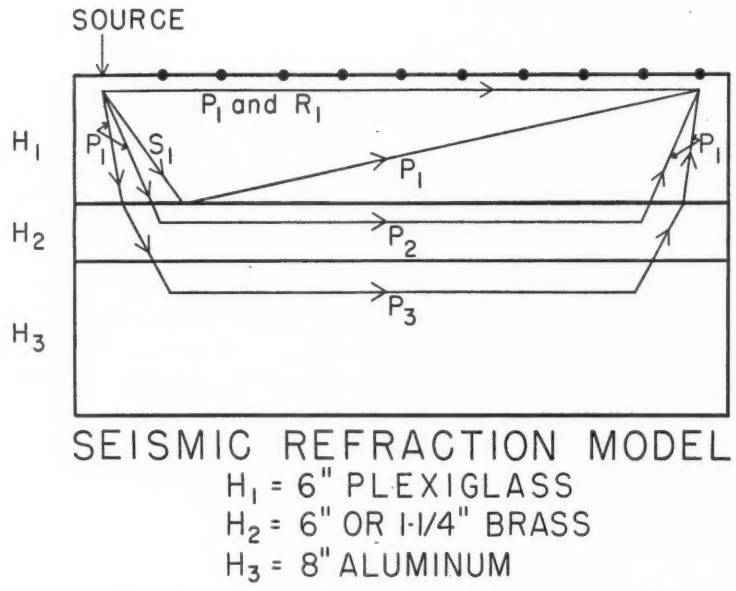

FIG. 8. Types of waves observed in triple-layer model.

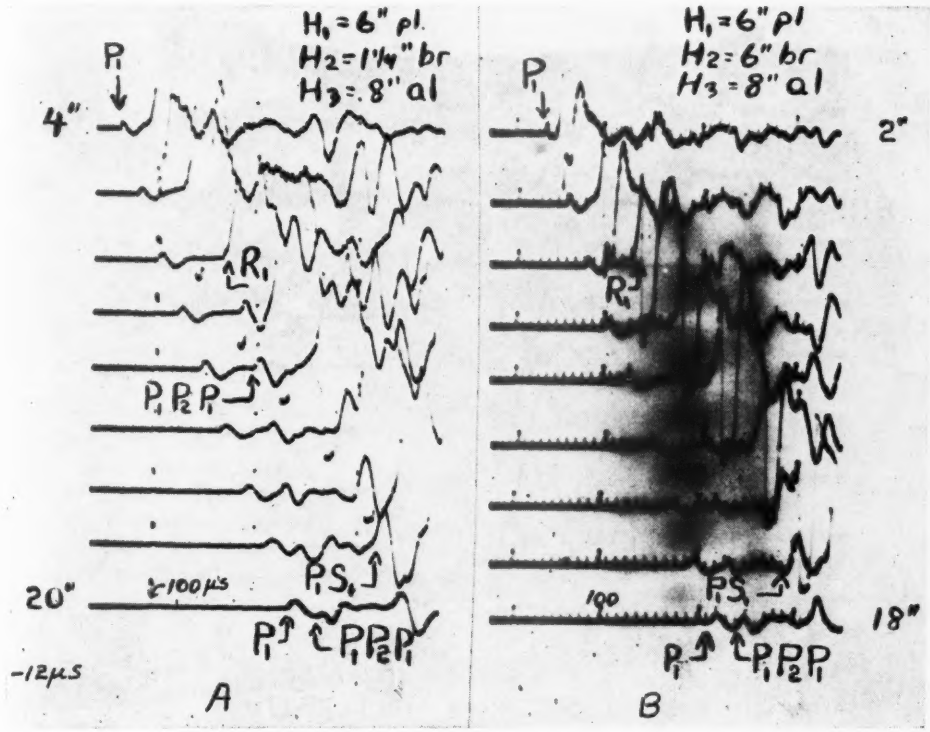

FIG. 9. A. Seismogram for spread 4–20 inches on triple-layer model, Case I. B. Spread 2–18 inches, Case II.

increasing distance, however (Fig. 10), the character of these arrivals changes profoundly. For Case I at distances greater than 24 inches $P_1P_2P_1$ and P_1 are overtaken by the weak high-frequency aluminum refraction $P_1P_3P_1$. The only event following $P_1P_3P_1$ on the seismogram for these distances is a large amplitude low-frequency wave $P_1P_{32}P_1$ which plots in Figure 13 with a velocity of 15,250 ft/sec, intermediate to that of brass and aluminum. This event is a prominent feature of the seismogram at all distances greater than 24 inches. It is interpreted as a "composite refraction" which because of its long wavelength has a velocity determined by the elastic properties of both the second and third layers. For the thick refracting layer of Case II, $P_1P_2P_1$ maintains its impulsive beginning after it emerges as a first arrival but increases in complexity with distance. However it continues to plot with a velocity appropriate for brass. At 40 inches the aluminum refraction $P_1P_3P_1$ emerges as the first arrival. An attempt was made to pick $P_1P_2P_1$ as a second arrival in the range 56–64 inches for Case II. Although a sharp event $P_1P_{23}P_1$ is present on the seismogram its velocity of 13,900 ft/sec is again too high for brass. The phase $P_1P_{23}P_1$ is also interpreted as a composite refraction, with velocity closer to that of brass than was the case

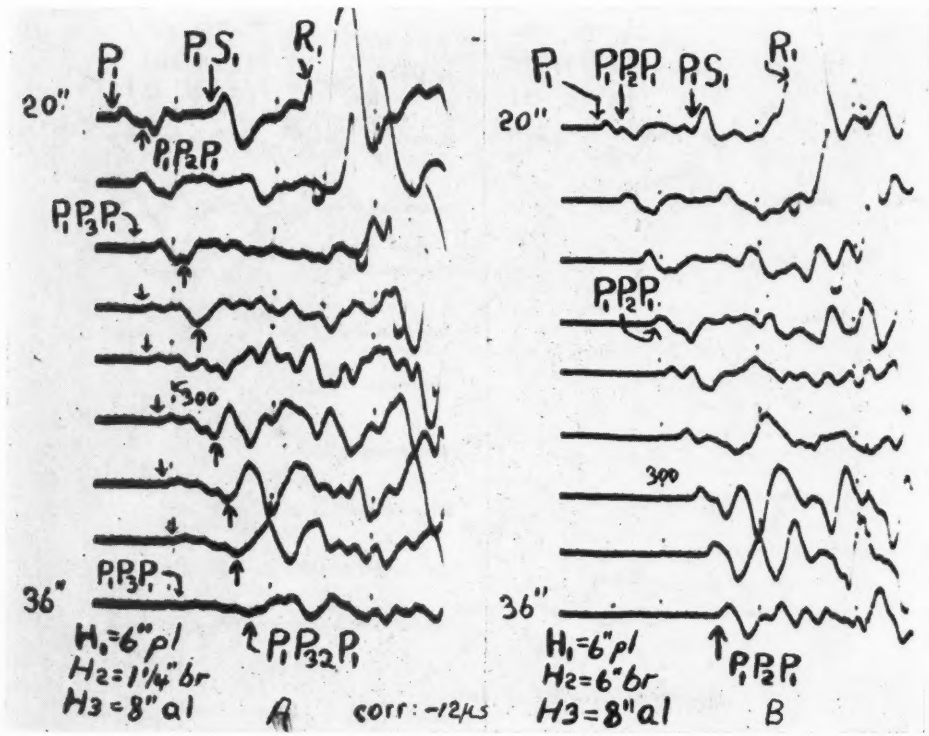

FIG. 10. A. Seismogram for spreads 20–36 inches in triple-layer model, Case I. B. Case II.

with $P_1P_{32}P_1$, indicative of the smaller value of λ_2/H_2. These results for $P_1P_2P_1$ suggest that only at relatively short shot-detector distances do refraction arrivals from a layer of finite thickness provide reliable velocity (and depth) determinations. At larger distances, especially when the refraction occurs as a second arrival, erroneous determinations of velocity may occur when the principal wavelengths of the refractions are large compared to the layer thickness.

An additional significant result is made evident by comparing the character and velocity of $P_1P_3P_1$ for Cases I and II. In Figure 12 it is seen that the character of these refractions is entirely different for the two cases and the travel time curve of Figure 13 indicates a velocity difference of about 2%. The identical sheet of aluminum was used for the P_3 refracting layer in both these cases so that differences in elastic constants or thickness of this layer are ruled out. One must conclude that even refractions from a very thick layer are affected by the layering in the overburden. This is not surprising in view of the somewhat analogous results of Officer (1953) for the refraction arrival in water covered areas.

Discussion

With great simplification we may ascribe the character of a refraction arrival to three factors: (1) the spectrum of the source; (2) absorption and scattering in

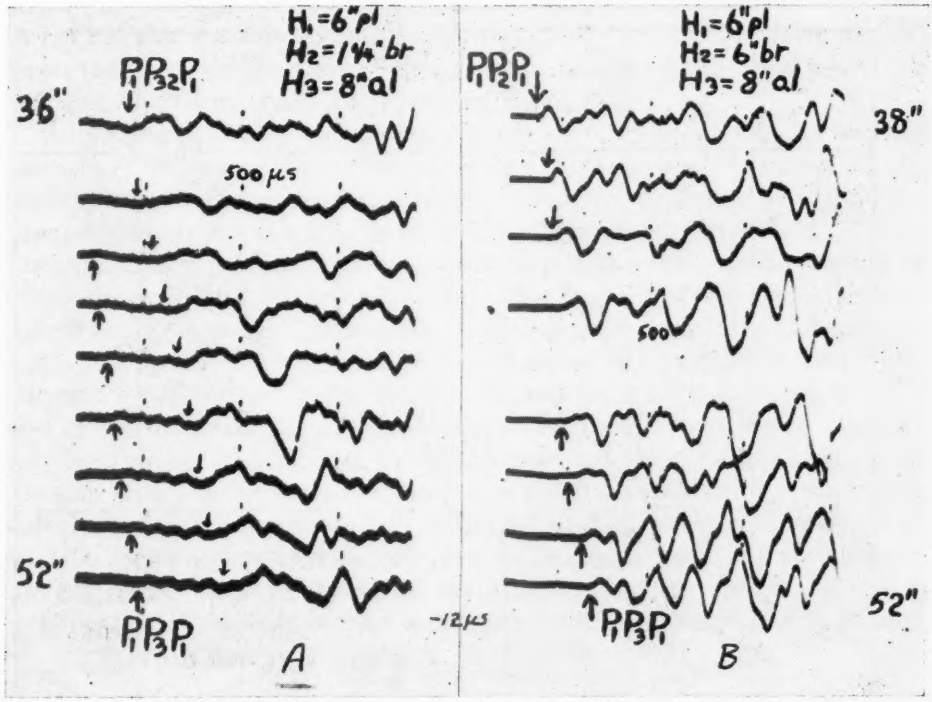

FIG. 11. A. Seismogram for spreads 36–52 inches on triple-layer model, Case I. B. Spread 38–52 inches, Case II.

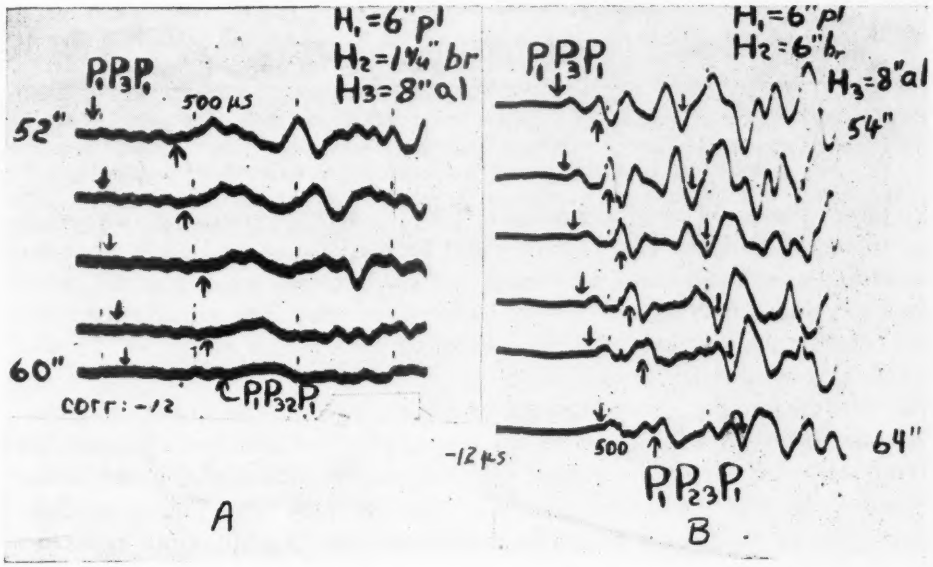

FIG. 12. A. Seismogram for spread 52–60 inches on triple-layer model, Case I. B. Spread 54–64 inches, Case II.

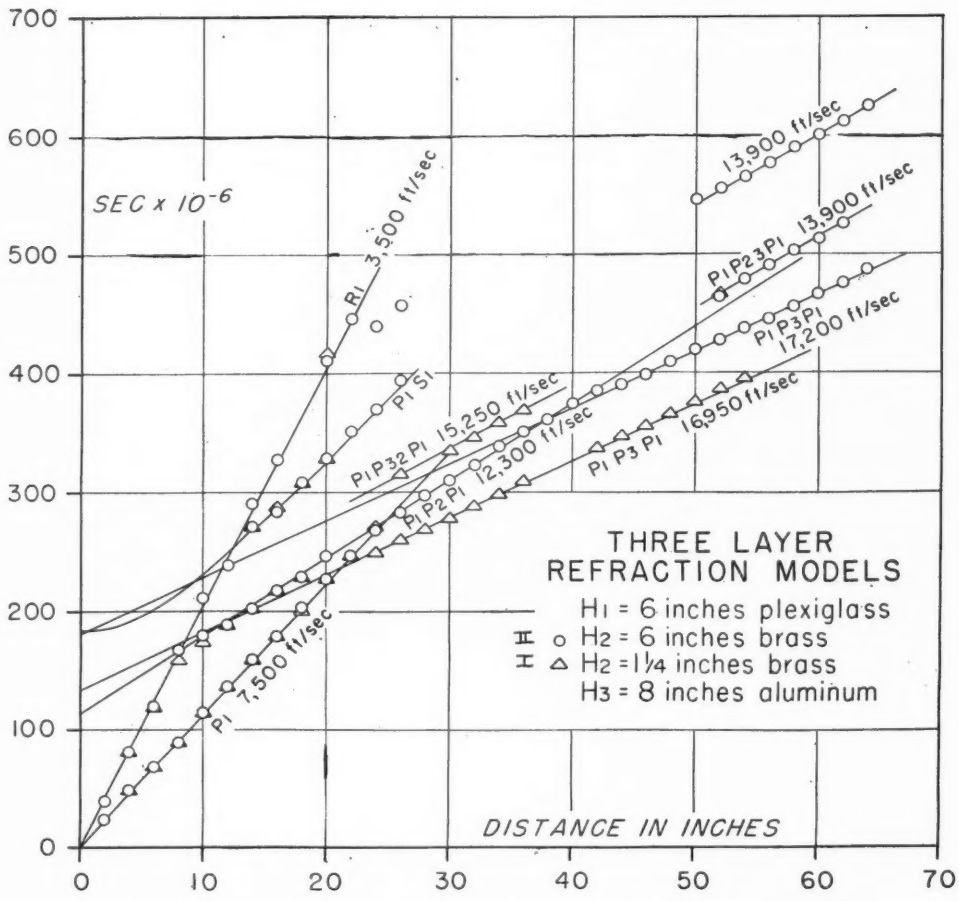

FIG. 13. Combined travel time curves for Cases I and II of three-layer model.

the layers above the refracting horizon; (3) the effects of transmission through the refracting horizon. This picture would be particularly applicable when the refracting layer is an excellent transmitter of elastic waves in contrast to an absorbing and scattering overburden. Under these conditions multiple reflection and constructive interference in the overburden need not be considered. Factors 1 and 2 determine the nature of the pulse delivered to the refracting layer. The third factor affects both the velocity and character of the refraction arrival. If predominantly low frequency energy is available for transmission through the refracting layer, our results suggest that the velocity determination can be unreliable if the ratio of wavelength to layer thickness is too large. This is especially true when refractions are picked as second arrivals. In addition an excitation function for horizontal transmission through the refraction layer also affects the relative amplitudes of the component frequencies that make up the refraction

arrival. Comparison of P_2 and $P_1P_2P_1$ in the two layer model suggests that this excitation function is related to the corresponding function for source and receiver in the transmitting layer. Excitation functions for special cases have been discussed by Pekeris (1948) and Press and Ewing (1950).

A common difficulty encountered in refraction shooting may be termed[2] "shingling" or "echeloning" of the travel time curve. Instead of plotting as continuous straight line segments the travel time curves appear as discontinuous, offset segments, the velocities indicated by the segments often being erratic. Although it is hazardous to extrapolate from our as yet too simple models to the more complicated conditions known to exist in the field, similar features are observable in the model. For example, had we decreased our initial pulse amplitude, or had we used a more absorbent medium for high frequencies than Plexiglass the $P_1P_3P_1$ refraction for Case I in Figures 10, 11, and 12 would not have been observed. Similarly the $P_1P_3P_1$ refraction for Case II in Figure 12 could not have been picked. In both cases a second arrival would have been plotted with a resultant echeloning of the travel time. The velocities indicated by the second arrival travel time segments $P_1P_3P_1$ and $P_1P_3P_1$ in Figure 13 are misleading and would certainly not agree with well-shooting determinations. The models show how echeloning can occur even under relatively simple conditions.

Other phases observed in these experiments will be discussed in later papers.

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[2] Terms used by Karl Dyk, personal communication, 1953.

GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 402–419, 13 FIGS.

FILTERING ASSOCIATED WITH SELECTIVE SAMPLING OF GEOPHYSICAL DATA*

C. A. SWARTZ† AND V. M. SOKOLOFF†

ABSTRACT

Geophysical data are often subjected to a variety of selective sampling operations in order to render their interpretation easier. The filtering effects of a number of commonly employed selective sampling procedures are discussed in detail in this paper.

Curves are given showing the frequency selectivity characteristics of several arithmetic sampling processes including simple averaging, successive differences, and residual curves and maps.

Instrumental sampling such as geophone mixing and electric filtering is also considered. The equivalence of electric filtering to an arithmetic sampling process is pointed out and illustrated by an example.

A recently developed statistical method of detecting seismic reflections is discussed as a sampling procedure and curves are presented to show the filtering action for two special cases under restricted conditions.

GENERAL

In the handling of large amounts of data acquired in the course of geophysical surveys, one of the major problems is that of separating the desired signals from the undesired noise. Noise is present in one form or another in all kinds of geophysical measurements and observations. For instance, in seismic prospecting, noise or undesired disturbances arise from the effects of wind, machinery, instrumental imperfections, scattering of energy by near-surface irregularities, and from other unwanted sources. In gravity and magnetic prospecting, noise arises from near-surface density and magnetic irregularities, from errors in surveying, from human errors in instrument reading, from magnetic storms, etc.

Moreover, what may be considered noise in one case may be the desired signal in another. In gravity work if we are interested in anomalies at great depth, say ten thousand feet or more, then the shallow anomalies constitute noise. If we are interested in the shallow anomalies, at a depth of a few thousand feet, then the deep anomalies exert a disturbing background influence which may be considered as noise. The definition of noise is, therefore, a relative matter depending upon what we are trying to do.

A few methods commonly employed to reduce the effects of noise are the following: electrical filtering in seismic amplifiers, grouping of geophones on the ground, compounding or mixing of traces on seismic records, averaging the arrival times of reflection or refraction events, and the preparation of residual gravity and magnetic maps.

As a matter of fact, the basic data are usually already averaged, or mixed, when we get them. For example, in seismic surveying the measured times are

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the result of travel through a complex medium of highly variable velocity which we usually approximate by assuming a constant velocity, or a linear increase, or some other relatively simple type of uniform velocity variation. In gravity and magnetic work each measurement is the integration or weighted average, of the combined effects of all gravitational and magnetic bodies in the neighborhood. This inherent averaging or mixing of the data at the source by no means lessens the difficulties of interpretation since it is usually of an undesirable type.

It is of interest to examine some of the numerous methods of selectively sampling data and to show how such procedures can be made to act as filters which tend to separate the signal from the noise. Now, it is at once evident that in the sampling process no new information is added; on the contrary, information may be removed from the data. The purpose of selective sampling, therefore, is to segregate the good from the bad, usually on the basis of frequency characteristics, so that the useful parts can be recognized and interpreted. The process is one of raising the signal-to-noise ratio. When this is done, however, the signal itself usually suffers a certain amount of degradation in quality with resultant loss of resolving power. Nevertheless, the over-all effect is often an improvement in our ability to analyze and interpret useful parts of the data.

SIMPLE AVERAGING

The curves of Figure 1 illustrate the effects of a simple type of sampling or averaging process. In this figure the composite curve, *D,* prepared by adding curves *A*, *B*, and *C*, contains high-, medium-, and low-frequency components. It is purely an arbitrary curve and does not represent an actual set of observed data. It may be thought of as a cross-section profile of seismic depth data, as a cross-section of a gravity map, or as a portion of a seismic trace. Curve *E* shows the result of making a running average of two consecutive equally spaced points along the composite curve. Curves *F*, *G*, *H*, *I*, and *J* are the result, respectively, of 3, 5, 7, 9, and 13 point running averages. The number of points averaged, and their spacing, is indicated by the symbols at the left of each curve. In each case the spacing between points is uniform and the average value is plotted at the center of the group.

These curves show that as the number of points in the running average is increased, first the higher frequencies disappear, then the medium frequencies, and finally (in curve *J*) only the lowest frequencies are retained, and they are partially attenuated. This type of sampling, therefore, has the effect of filtering out the high frequencies and retaining the low.

This filtering action may be illustrated more precisely by the curves of Figure 2. Curve *A* of this figure was derived theoretically to show the effects of carrying out a running average of two points, spaced apart by a distance δ, on any arbitrary curve such as the composite curve *D* of Figure 1 (δ may represent a time or a distance interval). This latter curve may be considered to be built up of many sine wave components covering a range of frequencies. The running average

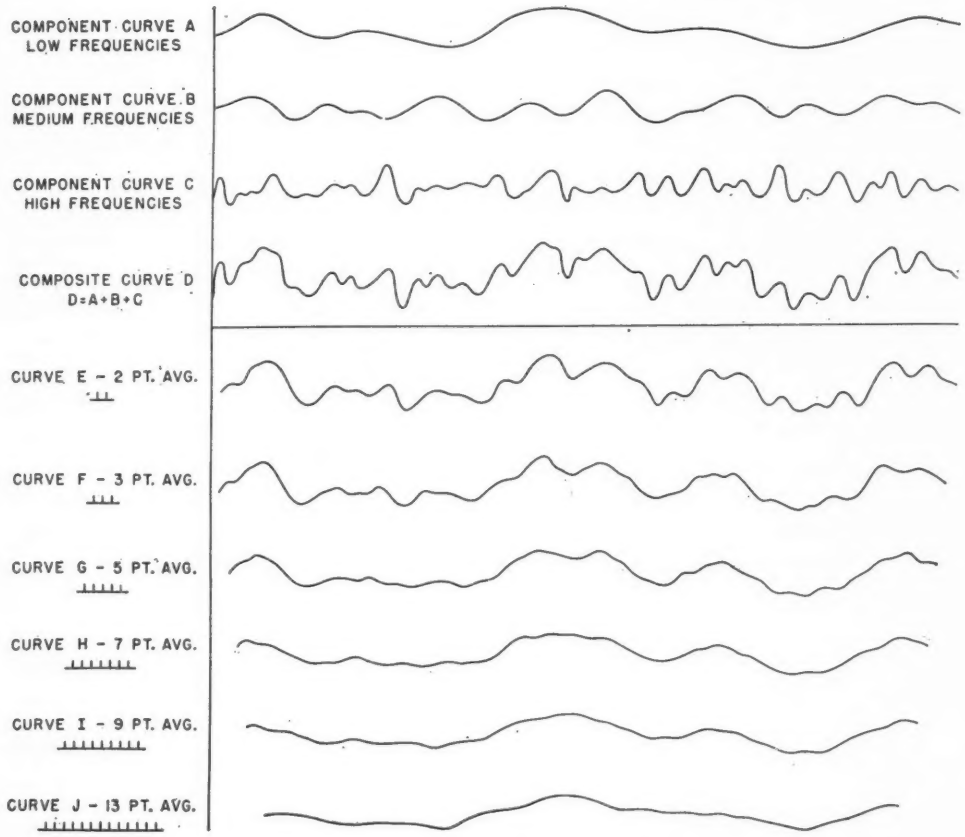

FIG. 1. Experimental averaged curves.

operator may be considered to operate on each component separately and then to add all the results to give the final output. Curve A of Figure 2 illustrates the relative selectivity of this operator for various pitches or frequencies of the component sine waves. It shows how the ratio of the normalized amplitudes of the output components to the corresponding input components varies as a function of frequency. The frequency or pitch scale, plotted along the horizontal axis, is in terms of the frequency unit $1/\delta$.

Curve A' shows the same data plotted as a function of wave length or period in terms of the unit interval δ. The frequency scale may be of more interest to one concerned with instrumental or electric circuit problems, whereas the wave length, or period, scale is probably of more interest to one who handles contour maps and cross-sections.

Curves B, B' and C, C' of Figure 2 are curves of a similar nature for three point and five point averages. Each of the frequency response curves is periodic, of period $1/\delta$, and continues indefinitely to the right. The wave length or period

response curves approach the value unity at the extreme right. In practice the value of δ is usually chosen small enough in relation to signal wave lengths or periods so that we are interested only in the first few repeated cycles of the frequency response curves and only the last few cycles of the wave length curves. These curves show quite clearly the effect already observed in the experimental curves of Figure 1, namely, that as the number of points averaged is increased, more and more of the higher frequencies are removed, while the lowest frequencies are retained.

SUCCESSIVE DIFFERENCES

The curves of Figure 3 show the effects of another type of numerical sampling or weighted averaging. These curves were prepared by first tabulating discrete values at the unit interval δ along the full length of the composite curve D of Figure 1. Then the differences between successive values in this series were tabulated to form a set of first differences. Differences of these values were then tabulated to give a set of second differences, and likewise a set of third differences was found. These first, second, and third differences were then plotted in the form of the curves A, B, and C respectively.

The symbols representing the running average pattern for each case are shown at the left of their respective curves. The vertical line segments show the

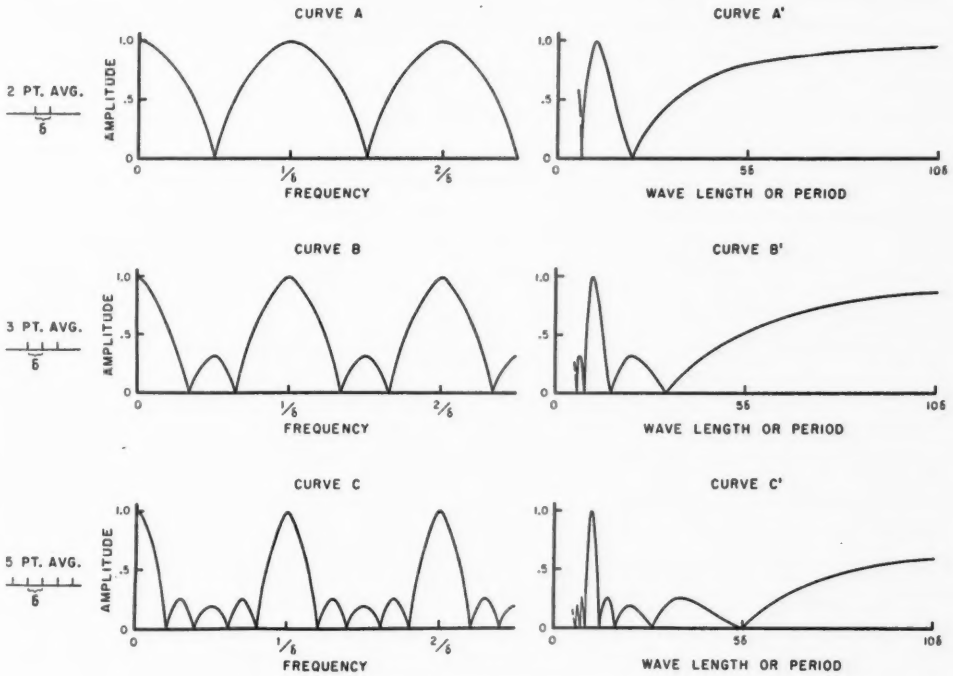

FIG. 2. Filter curves for simple averages.

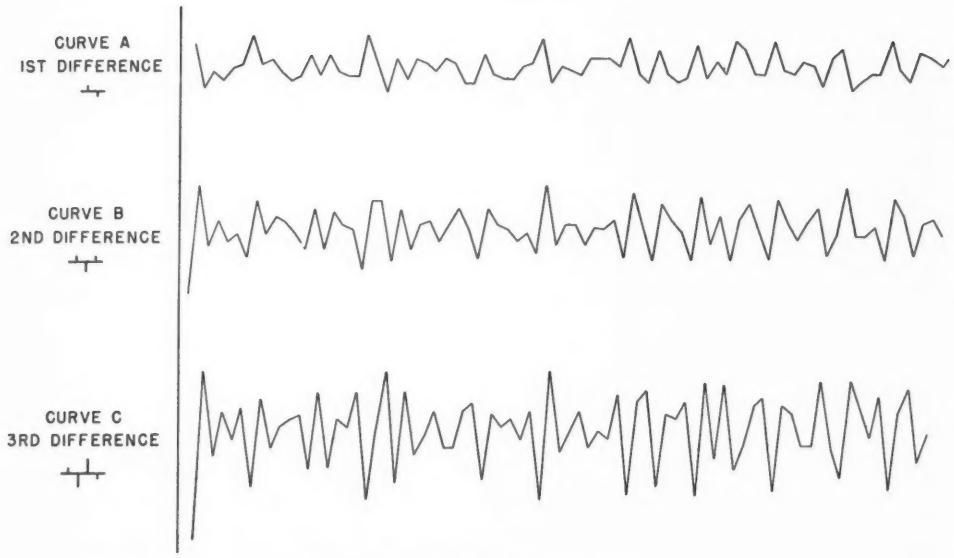

FIG. 3. Experimental difference curves.

spacing of the sampled values. A segment above the horizontal line indicates addition, one below, subtraction. The height of a segment indicates the associated weight or proportionality factor. If the interval δ between successive discrete values, in the first set of samples taken from the composite curve, were infinitely small, then curves A, B, and C would show first, second, and third derivatives. However, since the separation is actually the finite increment δ, they are not true derivatives except where the variation in the original curve is sufficiently slow.

What these curves show is that as we take successively higher differences the response oscillates with increasing amplitude, and that not only the highest but also the lowest frequencies suffer destructive interference. The principal low frequencies retained group themselves about an intermediate frequency whose wave length or period is 2δ.

This effect is more clearly brought out in the theoretical filter curves of Figure 4. The curves A, A'; B, B'; and C, C' show the relative amplitudes of retained harmonic components as a function of their frequency and of their wave length, for first, second, and third differences respectively. It is evident that all components whose wave lengths are greater than 2δ, and most of those smaller than 2δ, suffer attenuation, while those concentrated about 2δ are unaffected.

If the composite curve D of Figure 1 were a smoothed curve drawn through a series of points representing discrete observations separated by the uniform interval δ, and if these observations were subject to random errors, then the shortest periodic effect which these random errors could superimpose upon the observed curve would have the period 2δ. The curves of Figure 4 then show that

as successive differences are taken the longer wave lengths or periods corresponding to the desired anomalies in the curve of plotted observations are rapidly attenuated while the random errors themselves are brought out more distinctly with each successive difference. In other words, this procedure would tend to eliminate the broad, smooth anomalies being sought while bringing the random errors clearly to light, thus permitting their detection and measurement. Numerical methods whereby this property of successive differences may be utilized to give a measure of the probable error of the set of observations have been described by McCollum (1952).

GEOPHONE MIXING

The mixing of geophone output signals, or corresponding amplifier output signals to the oscillographs, is a common method for eliminating certain unwanted waves in seismic prospecting (Johnson, 1939). The curves of Figure 5 show the filtering effects of this procedure for waves, such as "ground roll," travelling horizontally and parallel to the geophone spread, when the outputs of three, five, or a very large number of geophones are mixed together. The carry-over from one geophone to the next adjacent one is assumed to be 40%. The

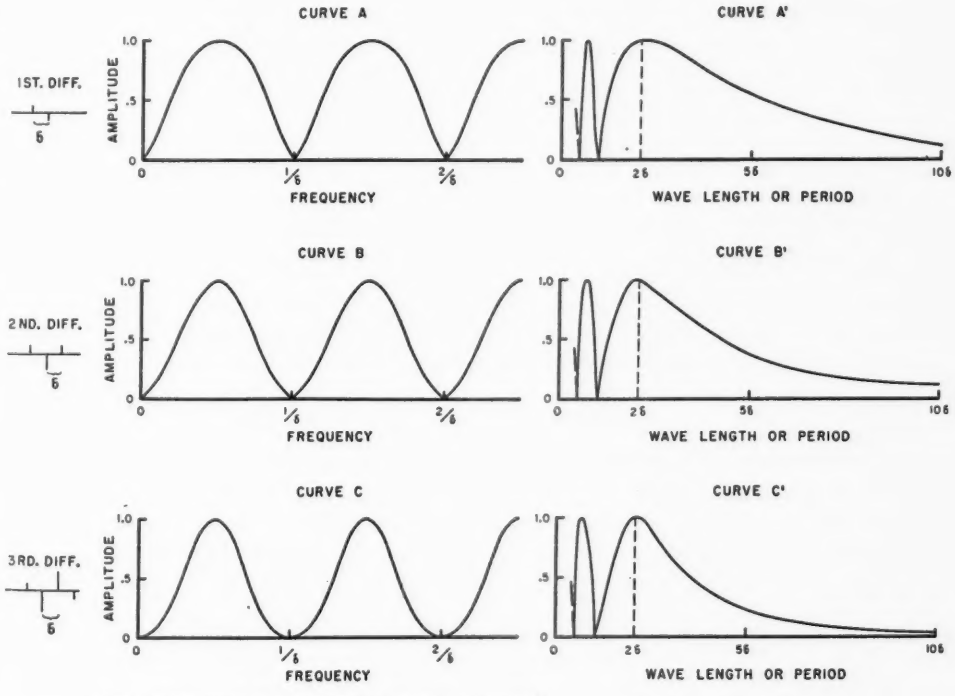

FIG. 4. Filter curves for successive differences.

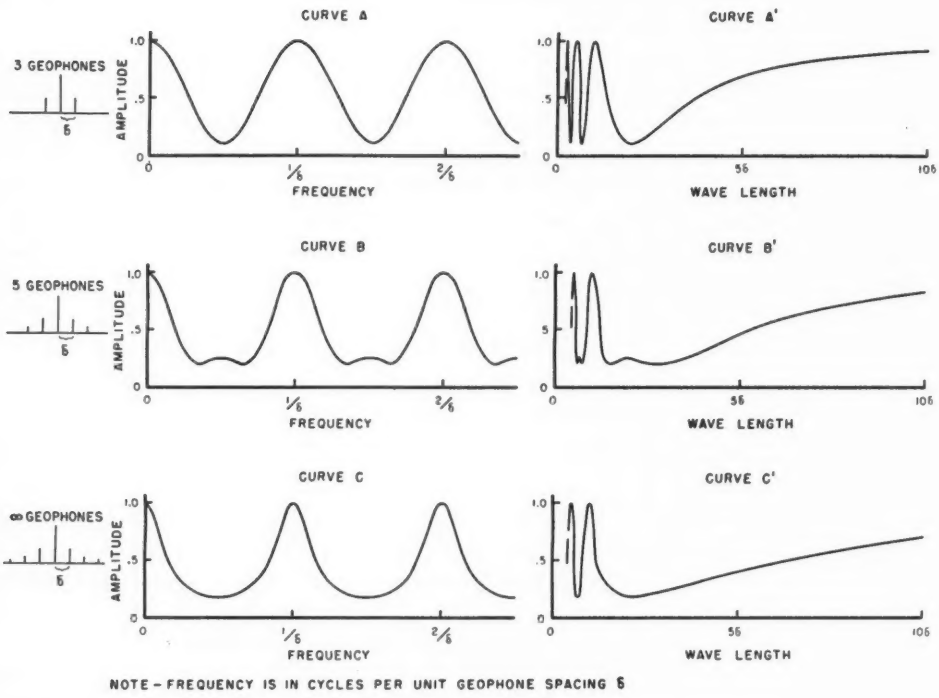

FIG. 5. Filter curves for geophone mixing with 40 percent carry-over.

curves are plotted in terms of both frequency and wave length. The symbols at the left of each curve show the spacing and relative contributions of each of the mixed geophones.

It is evident from these curves that in each case the longest wave lengths are always retained but, as the number of mixed geophones is increased, the minimum response trough in the vicinity of wave length 2δ becomes broader. For suppression of "ground roll," the geophone spacing δ should be made equal to one half the wave length of the principal "ground roll" component.

RESIDUAL OR DEPARTURE CURVES

Another type of weighted sampling is illustrated by the curves of Figure 6. Curve *A* of this figure was prepared by averaging three consecutive, uniformly spaced values along the compositve curve *D* of Figure 1 and subtracting this average from the middle value. This may be considered as a running-weighted-averaging procedure which continuously measures the departure of each value on the curve from the average of the values in its immediate neighborhood. Curves *B*, *C*, and *D* were prepared in a similar manner by averaging uniformly spaced values over wider and wider ranges and subtracting this average from the middle value. The sampling pattern symbol is shown at the left end of each curve.

The frequency selectivity of this process is readily seen in the curves *A*, *B*, *C*, and *D* of Figure 6. When only a few points are averaged, as in curve *A*, only the higher frequencies are retained. As the number of averaged points is increased, and the averaging range is enlarged, lower and lower frequencies are added until curve *D* is practically a duplicate of the original composite curve of Figure 1 with which we started.

It is evident that this procedure refers the magnitude of each value on the curve to the average in its surrounding neighborhood, rather than to a constant datum. The number and spacing of the points averaged determines the size of the neighborhood and, in effect, this local neighborhood influence is eliminated. The process is a close analogy to the preparation of residual gravity and magnetic maps where the purpose is to remove the larger regional background anomalies and to bring out the smaller and more significant features.

The theoretical curves of Figure 7 show more clearly the filtering effects of this type of weighted average. Curves *A*, *A'* and *B*, *B'* are the frequency and wave length response curves for two and four point running averages subtracted from a middle value. They indicate clearly the selective characteristics already seen in the experimental curves of Figure 6. That is, as we increase the number of averaged points and their range, additional high and low frequencies are admitted. Curves *C*, *C'* are for a slightly different sampling pattern in which an average over a wide range is subtracted from an average over a narrower range. In this case the filter curves are somewhat more complicated than *A* and *B*.

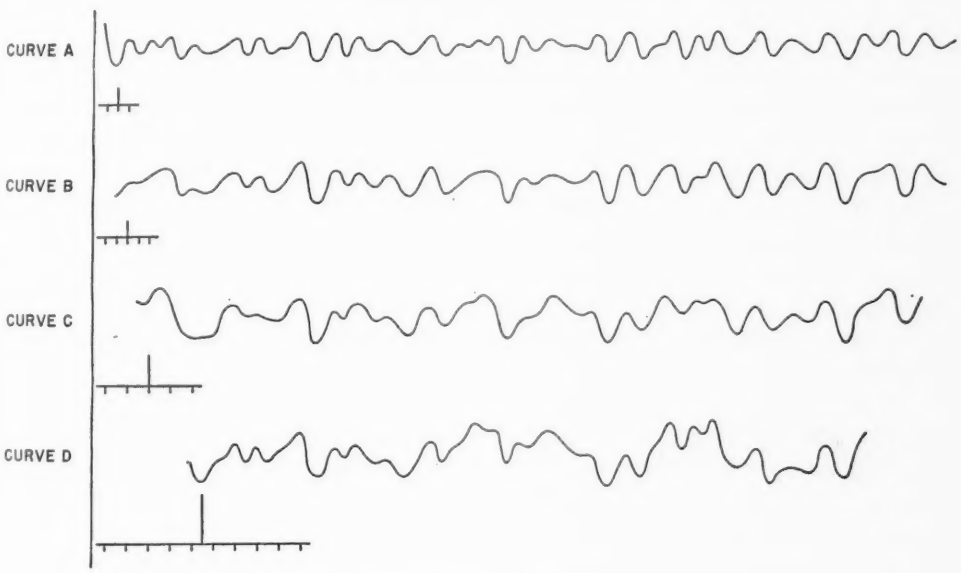

FIG. 6. Experimental departure curves.

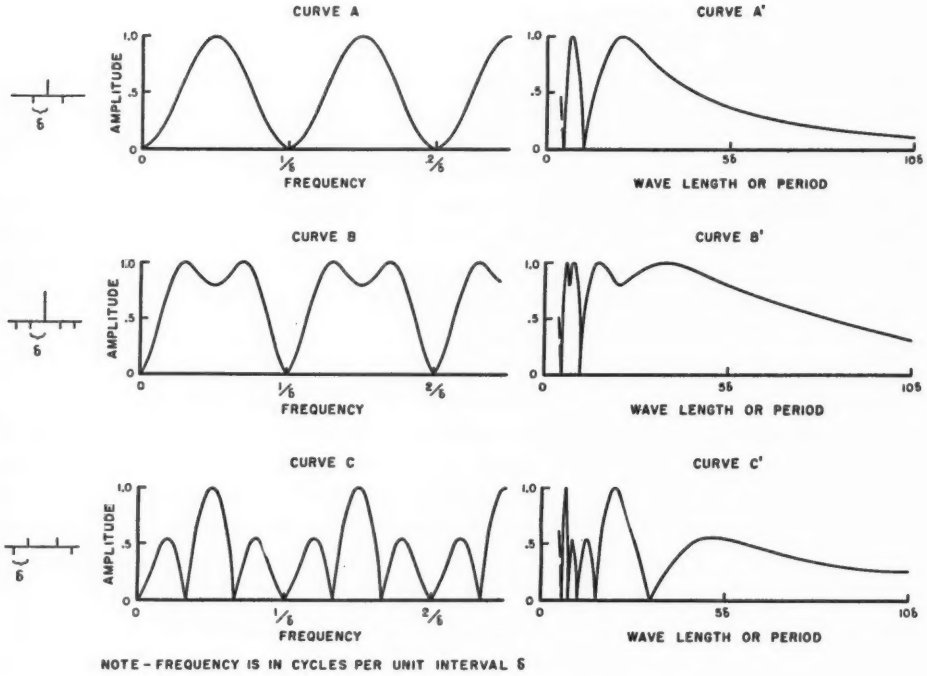

FIG. 7. Filter curves for departures.

ELECTRIC FILTERING

It is well known in the theory of electric circuits that the action of any linear electric filter is completely determined by its characteristic response to a standard input in the form of a unit "spike" impulse. Then its response to any arbitrary input may be found by considering this input as an infinite succession of narrow "spike" impulses, each of which contributes its own individual output component, which then add together to produce the total response. This process may be stated mathematically in several different ways. For instance, it is sometimes described as a Duhamel integral based on the principle of superposition in linear systems, as a cross-correlation between the unit response function (reversed in time) and the actual input function, or as a convolution or *Faltung* between these two functions.

This concept of filtering is a very general one and can be applied to any electrical, mechanical, optical, or other type of physical system which is linear, or it can be applied to data in numerical or graphical form (Piety, 1942). Physically, it is equivalent to a continuous running selective sampling of the input data. For instance, if the input is in the form of numerical or graphical data, then the sampling processes already discussed are examples. If the input data are available in the form of a magnetic recording, or a variable density photographic film, then

they may be selectively sampled, or scanned by means of an arrangement of multiple magnetic pickups or by multiple optical slits. In the optical case the slits may be of variable height and spacing or they may be combined into a single wide aperture of variable height shaped in such a way as to duplicate any desired scanning function or unit response curve.

Figure 8 illustrates graphically the process of electric filtering by performing a cross-correlation between an input function $E(T)$ and a unit "spike" response function $A(\tau)$. The upper part of the figure is a graph of a unit response function $A(\tau)$ which characterizes a given filter; the lower part shows how this function is reversed in direction and correlated with the input function, $E(T)$, which may be a seismic trace or other transient wave form. At any particular time, t, the output of the filter is the sum, or integration, of the products of all values of $A(-\tau)$ and $E(T)$ at all times prior to the time t. By displacing the curve $A(-\tau)$ with respect to the input curve $E(T)$, along the T-axis, and performing the summation at each displaced position, the complete output of the filter for all values of t is obtained.

Figure 9 shows how a relatively simple sampling procedure can be made to duplicate closely the filtering effects of an electric filter. In this figure, solid curve A is the response curve of a certain filter to a unit "spike" impulse. Curve B is an arbitrary input curve. In this case it is actually a Ricker (1953) pulse which

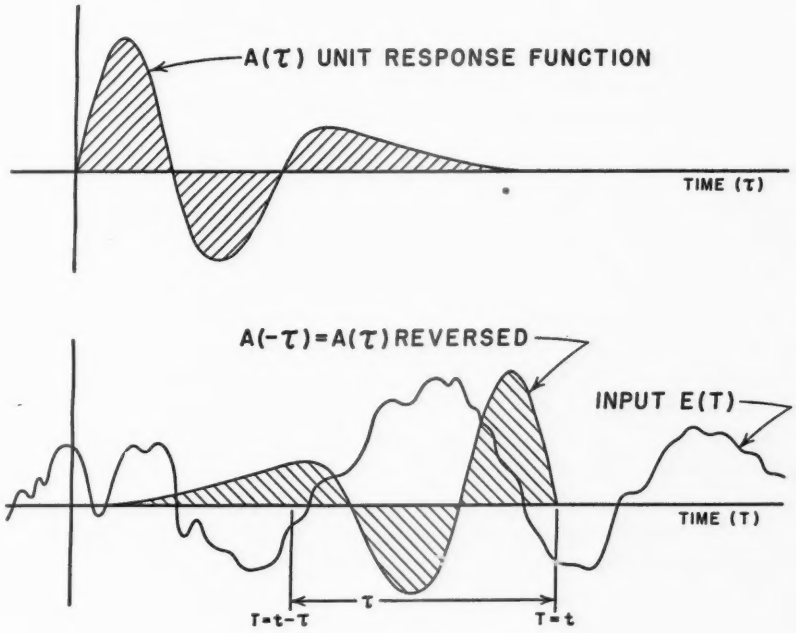

FIG. 8. Cross-correlation and filtering.

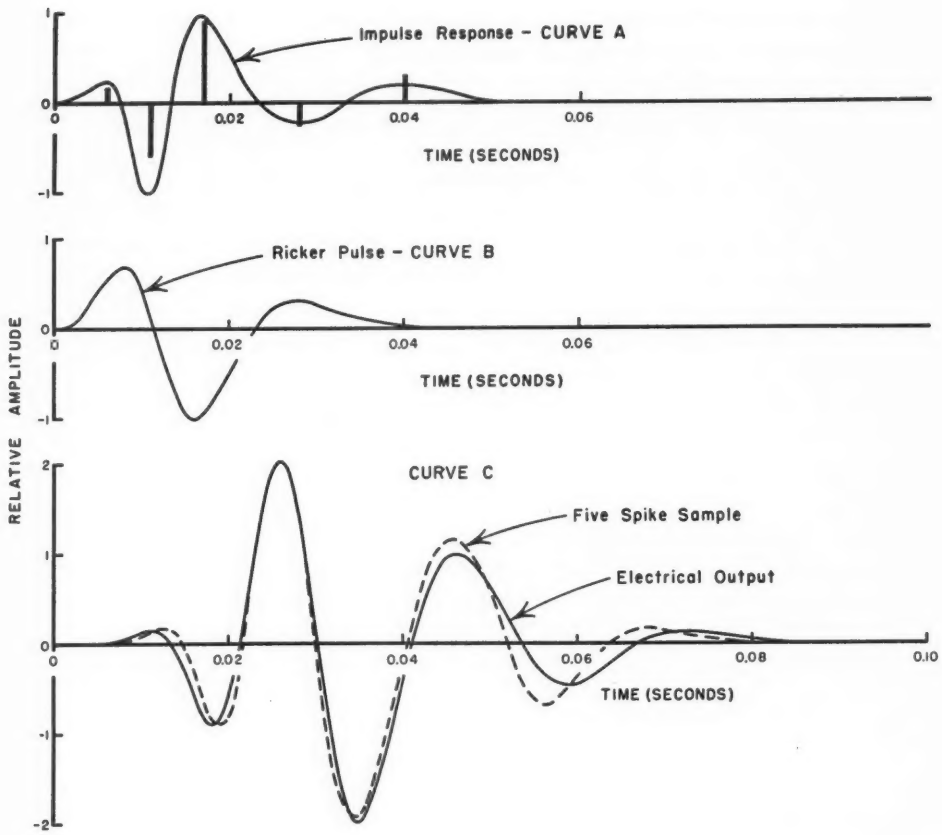

FIG. 9. Selective sampling vs. electric filtering.

is assumed to represent a seismic wavelet. Solid curve C is the output of the filter when curve B is the input. All three of these curves were traced from oscillograms of actual electric transients. Now if the curve B is recorded on a magnetic tape it can be readily sampled by means of an arrangement of spaced magnetic pickups. In order that the selective sampling, or scanning, procedure be a close approximation to the running correlation process of the electric filter, it is convenient to use five magnetic pickups, one for each peak and trough in the scanning function of curve A, and spaced at the centroids of the successive half-wave areas of this curve. Furthermore, the instantaneous response of each pickup may be made proportional to the area of its corresponding half-wave. The location of each pickup and its relative response is indicated by the position and height of the heavy black vertical lines on curve A. Now if the outputs of these pickups are added together (in proper phase), and the pickups are made to scan the full length of the input curve B, their combined outputs will generate a curve which closely approximates the cross-correlation between the curve A (reversed

in time) and curve *B*, such as was accomplished by the electric filter. If an infinite number of magnetic pickups could be used the magnetic scanning would exactly duplicate the electric filter action and would reproduce solid curve *C* exactly. With only five pickups arranged as here described, however, the reproduction (dashed curve) is very close as can be seen by comparing the dashed curve *C* with the solid curve *C*.

In the upper part of Figure 10 is shown a portion of a seismogram which was recorded on magnetic tape with a broad band filter. A fairly good reflection can be seen through the background of noise. In the lower part of the figure is the same recording after being scanned by four magnetic pickups arranged to simulate, as closely as possible, a filter whose response function matches the reflection itself. It has been shown by Wiener (1950, p. 95) that this is the optimum filter for detecting a very weak signal in very strong noise. Although the signal in this particular case is not weaker than the noise, it will be seen that the reflection is brought out clearly.

STATISTICAL DETECTION OF SEISMIC REFLECTIONS

In a recent publication (Wadsworth et al., 1953) a group working at the Massachusetts Institute of Technology described a statistical method of detecting reflections in a noisy seismogram. The procedure is illustrated, in part, by the diagram of Figure 11. In this diagram are drawn two hypothetical curves repre-

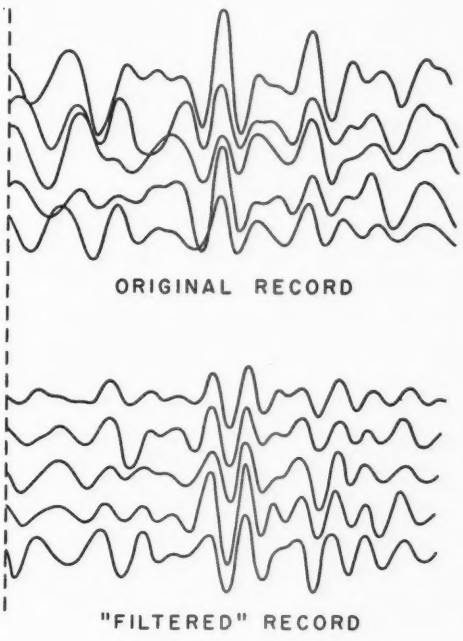

FIG. 10. Filtering by sampling.

senting adjacent traces on a seismogram. They are designated as the x and y traces. The basis of the statistical method is the process of "predicting" the displacement at a point on the x trace from several earlier displacements selected from both the x and the y traces. These prior values may be considered as selected samples. The predicted point on the x trace is indicated by the black dot at a'. The selected sample displacements at the points a_0, a_1, a_2, and a_3, on the x trace, and at b_0, b_1, b_2, and b_3, on the y trace, are all used to predict the displacement at the later point a'. Furthermore, it is assumed that the predicted value at a' is a linear combination of the eight previous sample values on traces x and y. The coefficients by which the eight samples are multiplied are A_0, A_1, A_2, A_3, and B_0, B_1, B_2, B_3, respectively. In the work which has been reported, the time interval between the sample values was uniform and equal to approximately 2.5 milliseconds. The predicted value, at a', is later than the latest sample value by a time interval of the order of 5 to 15 milliseconds.

In addition to these eight coefficients, another additive constant must be used in this linear prediction scheme in order to take account of possible differences in the origins with respect to which the displacements on the x and y traces are measured. Thus nine constants are needed, the determination of which constitutes a major portion of the work involved in the prediction computations. They are computed by a least squares method which determines them in such a

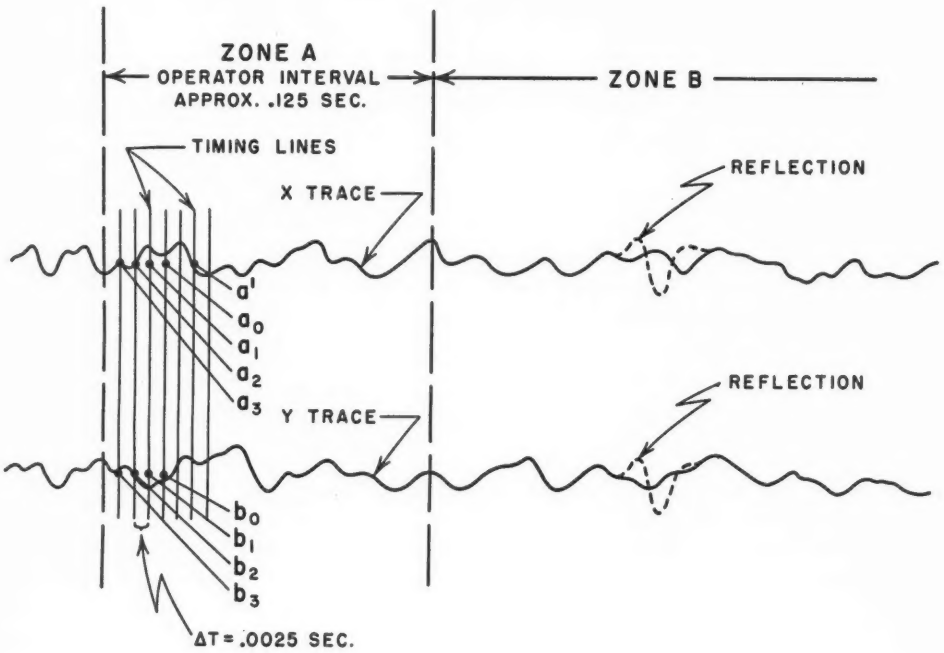

FIG. 11. Prediction mechanism.

way that the best possible fit between the predicted values and the actual values is obtained over a preselected operator interval designated as Zone *A* in Figure 11. This operator interval is usually about 125 milliseconds long. The prediction in this interval is the best possible in the sense that the sum of the squares of the departures of the predicted values from the actual values is a minimum. The operator interval is purposely chosen on a portion of the seismogram where no reflections can be seen. The operator corresponding to the nine computed constants is, therefore, the one which effects the best possible prediction of noise in the operator interval.

The next step is to take the difference, or departure, between the predicted value and the actual value at each point on the record. It is evident that this procedure will eliminate the noise from the seismogram in the most effective manner of which the method is capable—at least within the operator interval, or Zone *A*. Furthermore, if the application of the operator is extended into Zone *B*, and if the statistical distribution of the noise is the same in Zone *B* as in Zone *A*, then the noise will be very effectively eliminated in Zone *B* also. However, if a reflection should occur in Zone *B*, and if, as is usually the case, the statistical distribution of amplitudes within the reflection is different from that in the noise, then the operator should predict the reflection poorly, since it was designed specifically to predict the noise. As a consequence, when a reflection is encountered large departures will be obtained. These large departures are thus indicative of the presence of a reflection.

As a final step, the quantity which is plotted for visual observation, in order to study the effect of the operator, is not the departure itself, but the square of the departure. This step is a nonlinear process and has the advantage that all values obtained are positive so that reflections are indicated by high peaks. However, it has the disadvantage that it tends to destroy whatever similarity in character might exist between the departure values of the reflection and the reflection itself. This makes it more difficult to detect the reflection on the basis of its character in the customary fashion.

It is evident from this brief description that the prediction scheme is a selective sampling process. It differs from examples considered heretofore in that two separate sources are sampled and mixed to produce the output. It is not possible, therefore, in the usual sense, to represent the filtering effect of the composite operation upon the x trace alone, since the operator itself depends upon the y trace as well as the x trace. However, it is possible to get a fairly clear idea of the filtering effect by means of the following considerations. Let us assume that in Zone *A* there are no reflections present, the traces consisting solely of noise. Suppose, however, that in Zone *B* there is a reflection, and that it is exactly the same in shape, amplitude, and phase on both the x and the y traces. It is indicated in Figure 11 by the dotted portions of the traces in Zone *B*. Then the output of the above described operator (if we omit the final nonlinear step of squaring) may be considered to be the result of the operator acting upon two

independent components of the two traces, i.e., the noise component and the reflection component. So far as the noise component is concerned, it is clear that the operator has been specifically determined in such a way as to reduce the noise to an absolute minimum within the operator interval, Zone A, and it may be assumed that it will continue to do so quite effectively in the adjacent Zone B. With regard to the reflection component, however, the filtering effect of the operator can readily be represented by curves similar to those given in previous examples. This is possible because the reflection component is assumed to be identical on both traces. This is not a difficult situation to imagine as existing in practice; in fact, it may be considered as a fairly typical situation.

With these assumptions regarding the reflection, then, it is readily possible to set up the sampling pattern and compute the equivalent filter characteristics. The sampling pattern consists of four samples taken at intervals of 2.5 milliseconds with their relative contributions equal to A_0+B_0, A_1+B_1, A_2+B_2, A_3+B_3, and a fifth sample, 5 milliseconds later, whose contribution, A', is equal to minus one. It should be noted that the value of A' is always equal to minus one. Figure 12 shows graphically the sampling patterns for two actual operators determined by the MIT group at two different locations on a noisy seismogram. In addition to the sampling patterns there are shown also the frequency response curves. These curves can be approximated by equivalent electric filters whose

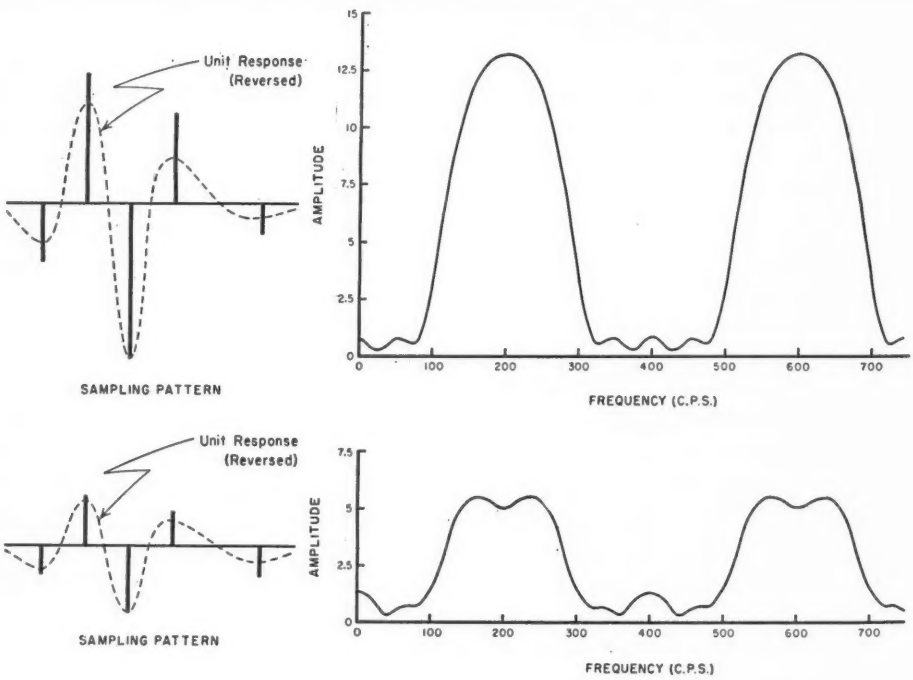

FIG. 12. Filter curves for prediction operators.

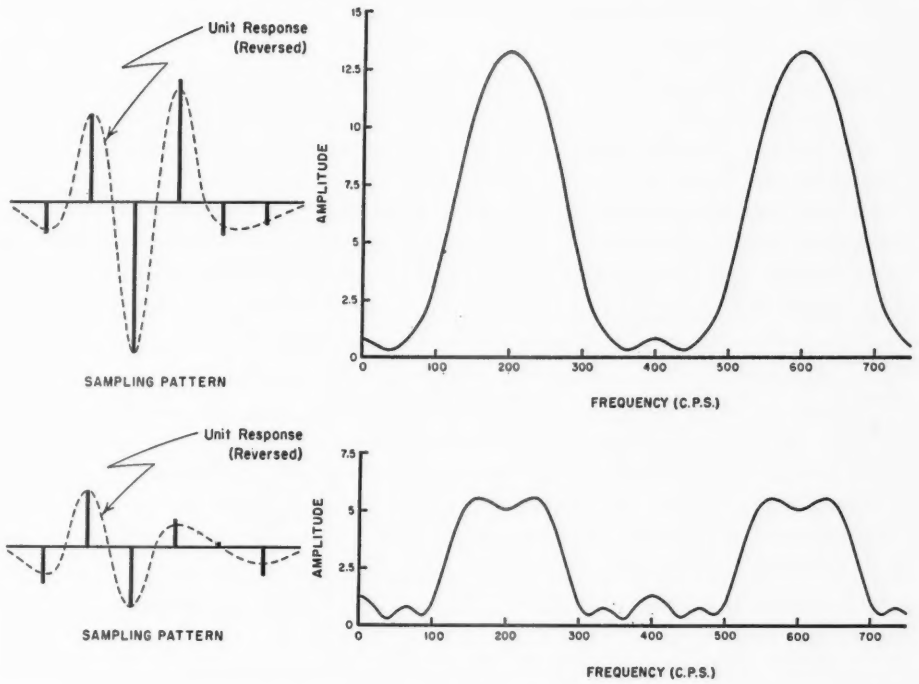

FIG. 13. Filter curves for prediction operators.

responses to unit "spike" impulses are similar to the dashed curves sketched in Figure 12.

In evaluating the filtering effect of the two curves of Figure 12, we may confine our attention to portions of the curves below one hundred cycles, since most seismic records do not contain frequencies appreciably higher than this. Within this frequency range it is evident that the filtering action of the two particular operators here plotted is not sharp.

It is now apparent that we can proceed a step further and determine the filtering effect, on the reflection, for a somewhat more general situation in which the reflection on the x and y traces has exactly the same form but may be different in amplitude and phase. For instance, suppose the reflection on the y trace has an amplitude only half as large as on the x trace, and suppose it appears 5 milliseconds earlier. In this case the effective sample pattern consists of the four samples from the x trace with contributions A_0, A_1, A_2, A_3, and four samples from the y trace with contributions $B_0/2$, $B_1/2$, $B_2/2$, $B_3/2$ taken 5 milliseconds earlier than the x samples, together with the A' sample on the x trace (for which A' is equal to minus one). Figure 13 shows the frequency response curves as well as the approximated unit response function of the equivalent electric filter for the same two prediction operators that were used in the preparation of Figure 12.

An examination of the curves of Figure 13 shows that they are quite similar to the curves of Figure 12.

One may easily speculate regarding various means whereby the sampling pattern of the prediction scheme can be modified in such a way as to not only eliminate the noise effectively but also to bring out the desired reflections more adequately.

It will be noted in Figures 12 and 13 that the first cycle of the repetitive pattern of the frequency response curves is symmetrical about the central frequency of 200 cps. Also, the sharp filter characteristics of the curves are in the frequency range above 100 cps. It appears that it might be desirable in some cases to modify the prediction scheme in such a manner as to cause the sharply peaked characteristics to fall within the frequency range below 100 cps. Two obvious methods for doing this come readily to mind.

One method is to increase the interval between the sampling values. This would leave the shape of the frequency response curve unchanged but would compress it along the frequency axis in the same ratio as the sampling interval is increased. For instance, if the interval were increased to 10 milliseconds instead of 2.5 milliseconds the frequency response curve would be compressed so that the central frequency would be 50 cps instead of 200 cps. This would be in a more desirable frequency range so far as the reflections are concerned.

Another possible procedure is to increase the over-all range over which the sampled values are distributed. This could be accomplished by using more sample values or by increasing the time lead between the predicted value and the sample values.

Whether or not these means for increasing the effectiveness of the prediction scheme as a filter for the reflections would be compatible with the necessary requirement that the scheme also suppress the noise effectively is a matter for investigation. Probably the optimum operator, which most nearly achieves the ultimate goal of maximum signal-to-noise ratio, would be a compromise between one which effects maximum noise suppression and one which most satisfactorily reproduces the signal.

PHASE CHARACTERISTICS

The filter curves presented here show only the amplitude response as a function of frequency. Similar curves could be prepared to show the corresponding phase characteristics. If the sampling pattern is a symmetric one, the phase shift is zero (Swartz, 1954); if it is antisymmetric the phase shift is constant for all frequencies and equal to 90°. If the pattern is unsymmetric it can be resolved into a symmetric component and an antisymmetric component (Goldman, 1948, p. 13) and the phase shift, in this case, is the angle whose tangent is equal to the amplitude of the antisymmetric (out of phase) component divided by the amplitude of the symmetric (in phase) component. In Figures 2, 4, 5, and 7 above, the sampling patterns are all either symmetric or antisymmetric, while those in Figures 9, 10, 12, and 13 are unsymmetric, as are most electric filters.

TWO-DIMENSIONAL SAMPLING

The foregoing selective sampling processes have been discussed with respect to their application to original data in the form of linear curves or cross-sections. However, the technique can readily be extended to data in two-dimensional form such as surfaces or contour maps. Some of the common methods of preparing residual gravity and magnetic maps are examples of two-dimensional selective sampling processes. The operations usually consist of replacing each value on a contour map by a new one which is a linear combination of selected values in the surrounding neighborhood. These selected values are usually arranged in a symmetrical pattern or array about the replaced value as center. An overlay template is often employed as an aid in selecting the proper values to use in the computation.

The filtering effects of a wide variety of these residual operators have been described in detail by one of the authors (Swartz, 1954).

ACKNOWLEDGMENTS

The authors are indebted to R. A. Peterson of United Geophysical Company, Inc., who initiated these investigations and contributed many of the ideas presented. We also wish to acknowledge the contributions of F. S. Kramer and the efficient help of Miss Helenita Officer, who carried out the computations and prepared the initial drawings. The final drafting was done by R. L. Duke.

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GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 420–437, 23 FIGS.

REVIEW OF PATTERN SHOOTING*

A. E. McKAY†

ABSTRACT

Patterns of shot holes and patterns of seismometers are now standard technique in many areas currently being surveyed by the seismograph. This paper reviews some of these pattern arrangements and shows comparison records in a number of areas such as New Mexico, West Texas, western Oklahoma, Mississippi, and Florida. Although pattern shooting is definitely proven as a useful technique, it is not to be construed as a cure-all for difficult shooting areas.

INTRODUCTION

This paper is a review of pattern shooting as used currently in difficult seismic reflection areas. Discussion is confined to the relatively new technique of shot hole patterns and the manner in which these patterns have been combined with complimentary patterns of multiple seismometers.

The review is largely pictorial with numerous record comparisons shown. The comparisons are made possible through the cooperation of a large number of oil companies and geophysical contractors who have contributed the records for the display. The release of such results for publication by so many companies is a real credit to the oil exploration industry. These companies are not identified individually; however, by their generous contributions we are able to see examples of what others are doing and perhaps compare with results of our own efforts.

Any review of pattern shooting, even though emphasizing shot hole arrangements, must include some mention of, and credit to, the older technique of multiple seismometers. Seismometers in groups of two or more per trace have been used for many years by geophysicists in their efforts to improve reflection data. As the demand has grown for more exacting data and as the industry has pushed farther into the known poor reflection areas, geophysicists have gradually come to use more and more seismometers per trace. In contrast to multiple seismometers, early results of multiple shot holes were discouraging; however, these early efforts to improve record quality by the use of simultaneous shots in more than one shot hole were entered into only half-heartedly and without the exhaustive approach characteristic of the current activity.

The present technique of using simultaneous shots in more than one shot hole at a single location was initiated more or less at the same time by a number of

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companies in the late 1940's. This followed closely after the advent of air shooting (Poulter, 1950) and eventually met with such success that the technique is now normal procedure in areas such as the Edwards Plateau of West Texas.

Most of the original patterns of shot holes and many of the seismometer arrangements were first designed by physicists. A great deal of the initial experimental work included attempts to measure interference frequencies and the design of patterns for their elimination. Later these original patterns were changed or approximated to suit field conditions or other operational requirements.

For those readers who have not previously examined the results of a pattern shooting technique a word of caution on two points may be of value. First, it should be recognized that the records shown are selected, and although in many cases they are representative, they are not necessarily average for each area shown. Neither are they typical of the improvement that can be expected in all areas. The pattern technique, although proven successful, is by no means to be considered a cure-all for difficult reflection areas. Secondly, since pattern holes are usually relatively shallow and do not always penetrate the near-surface low velocity layers, steps must be taken to secure an adequate weathering correction. In such instances it is customary with many operators to drill one hole of each pattern into the unweathered strata for an uphole time measurement, and, as a check on the uphole time, to compute the depth to the weathering interface from the refraction first breaks.

In most of the record comparisons to follow, the single shot hole records that are shown cover as nearly as possible the same surface and subsurface areas as the corresponding pattern arrangements. Circles indicate shot holes and crosses represent seismometers.

ANADARKO BASIN

The first area from which typical pattern shooting records will be shown is the Anadarko Basin in Western Oklahoma, where poor seismic results are well known. This is an area where the surface and near-surface formations are of the Quartermaster and Cloud Chief gypsum of the Permian. Figures 1 through 4 show the effect of pattern shooting in this area.

SOUTHEASTERN NEW MEXICO

The next area to be considered is southeastern New Mexico where the surface consists of sands, shales, and caliche of the Ogallala formation of the Tertiary. Figures 5 through 7 show records, both pattern and single hole, shot in this area.

MIDLAND BASIN

The next comparisons are from Ector and Midland Counties, Texas, located in the Midland Basin portion of the Permian Basin of West Texas where the surface or near-surface also consists of sands, shales, and caliche of the Tertiary with

some thin Cretaceous limestone remnants present. Figures 8 through 11 show records shot in the Ector-Midland County area.

EDWARDS PLATEAU

South of Midland is a broad area commonly referred to as the Edwards Plateau, where the surface formation is principally the Edwards limestone of the Cretaceous. This is a very hard, dense limestone that varies in thickness from zero to at least 500 feet. Seismic reflection results on the Plateau have been extremely poor, if not impossible, since the very early 1930's. The area has been considered a prolific oil province for many years, and the pressure for improving seismic operations has been enormous. In the early 1940's, refraction surveying techniques (Barthelmes, 1946; Gamburtsev, 1946; Gillin and Alcock, 1946; Harris and Peabody, 1946) were refined and a great deal of exploration was carried on by use of this method. Oil fields such as the Todd field in Crockett County, Barnhart

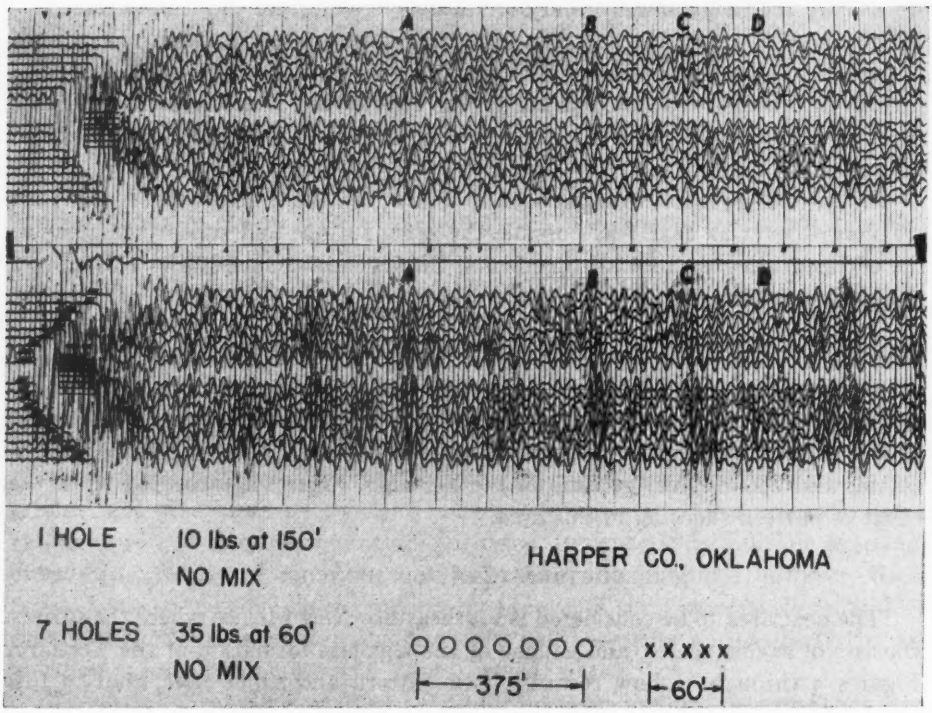

FIG. 1. Two records shot in Harper County, Oklahoma, with a common spread of five seismometers per trace. The surface spread extends approximately 1,320 feet in each direction from the shot hole and there is no instrumental mixing. The top record was obtained by firing 10 pounds of explosives at 150 feet and in the lower record seven 60-foot shot holes were used with 5 pounds per hole shot simultaneously. Letters "A," "B," "C," and "D" shown on these records represent reflections identified as Pawhuska, Oswego, Mississippian, and Ordovician respectively.

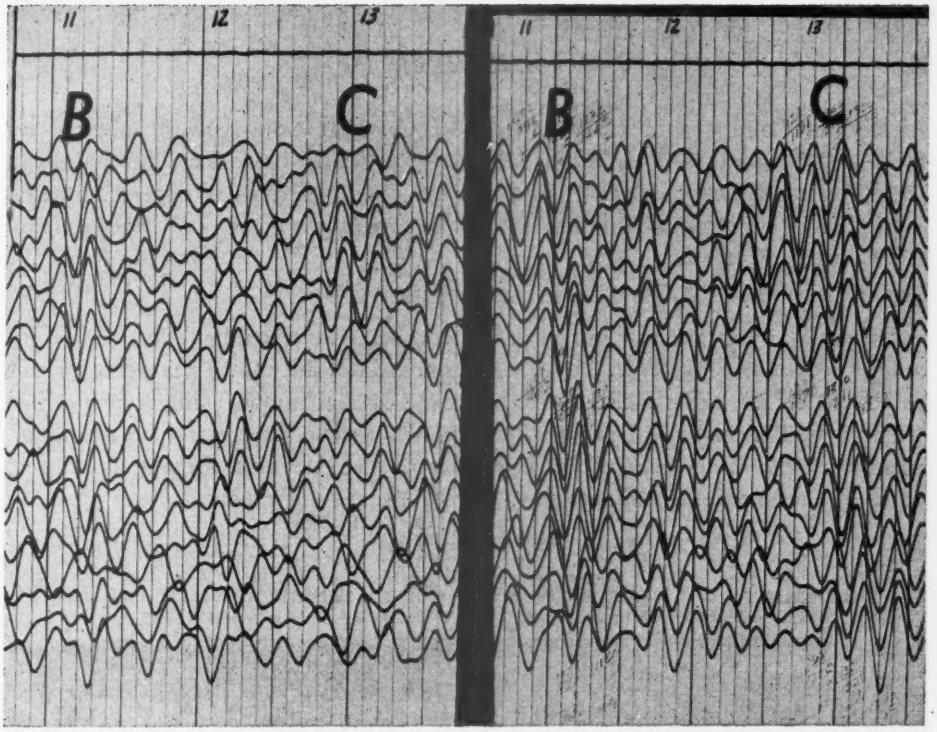

FIG. 2. An enlargement of the records in Figure 1 at Oread and Mississippian depth. The record on the left is from the single shot hole.

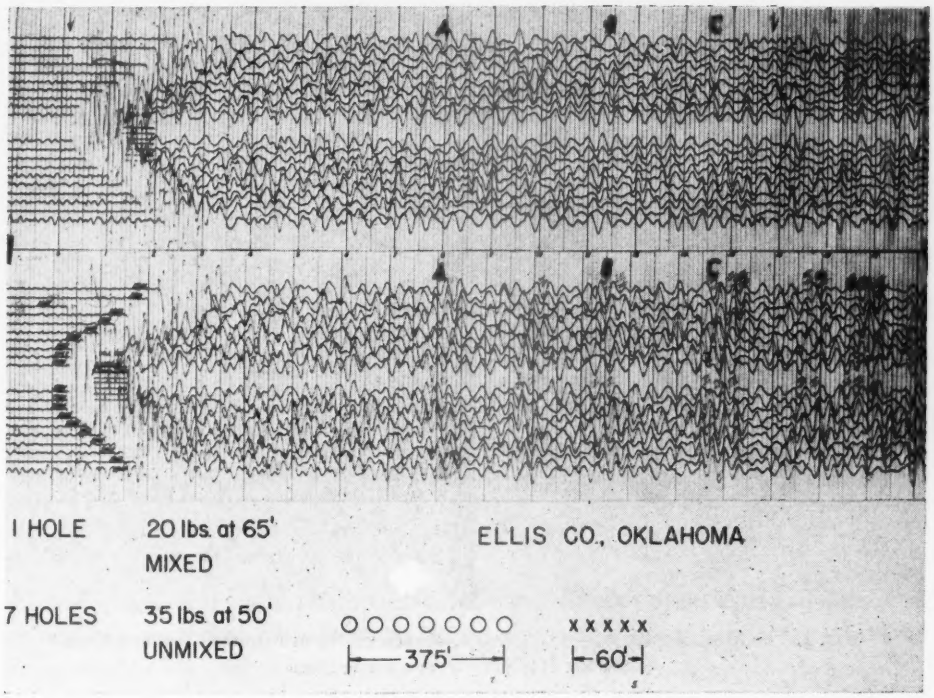

FIG. 3. Two records from Ellis County, Oklahoma, obtained with five seismometers per trace over the same surface spread. The top record is from a single hole shot with 20 pounds at 65 feet, and this record is mixed 50 percent. The lower record is from seven holes shot simultaneously at a depth of 50 feet with a total of 35 pounds of powder and with no mixing. "A" represents Pawhuska depth, "B" Oswego, and "C" Mississippian.

in Reagan County, and Midway Lane of Crockett County were mapped by refraction techniques. Refractions were only partially successful, however, and the Edwards Plateau became one of the first areas of extensive experimentation with pattern shooting techniques. Figures 12 to 19 show record comparisons from the Edwards Plateau.

WESTERN MISSISSIPPI

Figures 20 and 21 show records from western Mississippi in Jefferson County along the Mississippi River. These records are somewhat out of character for this review since the experimental work developed a technique using a single hole which would seem to be best for the area. A box-type arrangement of seismometers, with the dimensions of the box being 50 feet on a side, proved superior to an in-line seismometer arrangement. The figures are self-explanatory.

FLORIDA

The peninsula of Florida is also a very difficult seismic province, and shooting

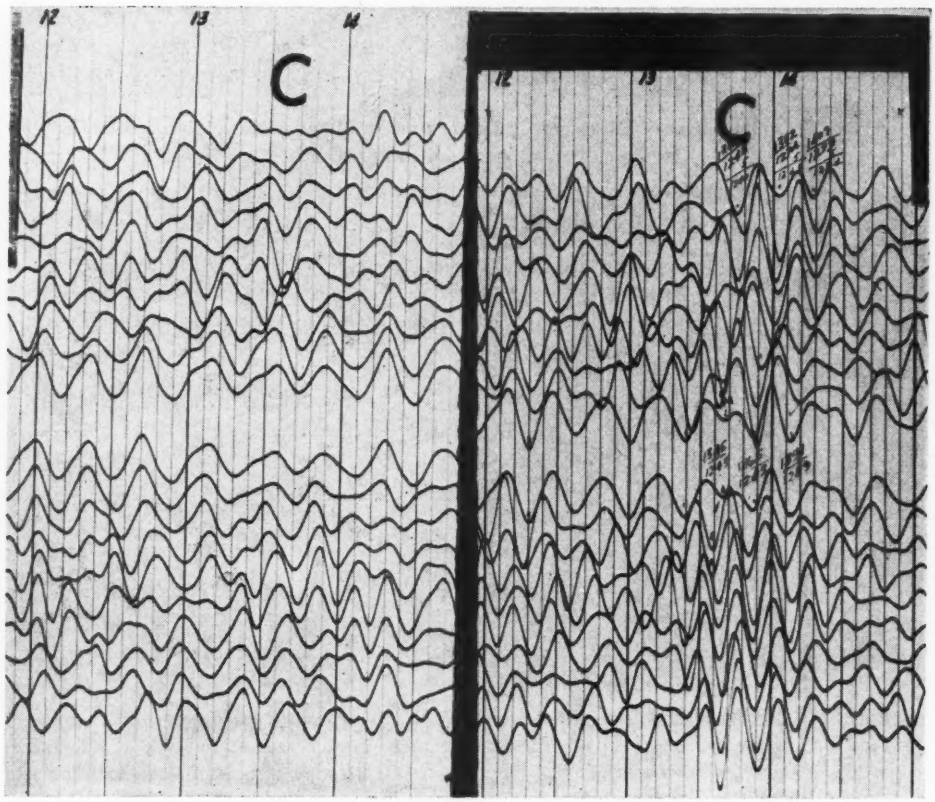

FIG. 4. The Mississippian portion, enlarged, of each record in Figure 3. The record on the left is the one from a single hole.

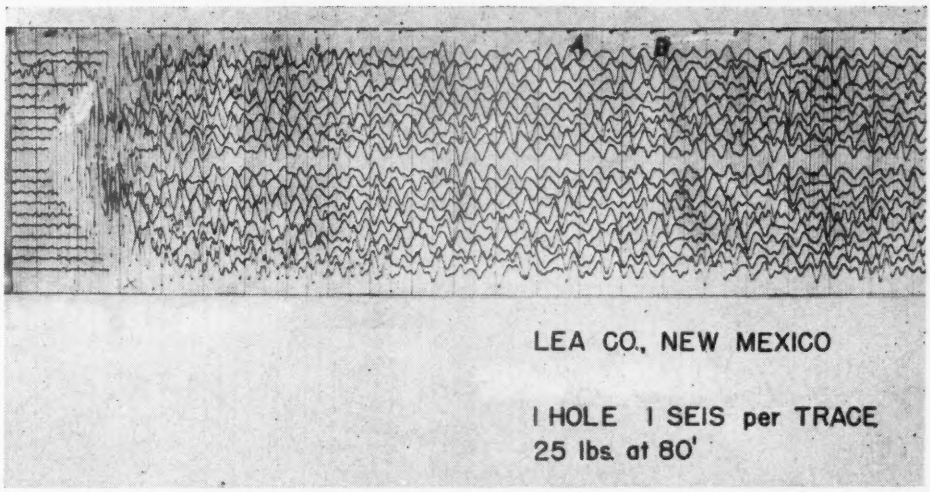

FIG. 5. Record shot with a single hole using 25 pounds at 80 feet and recorded with a single seismometer per trace in Lea County, New Mexico.

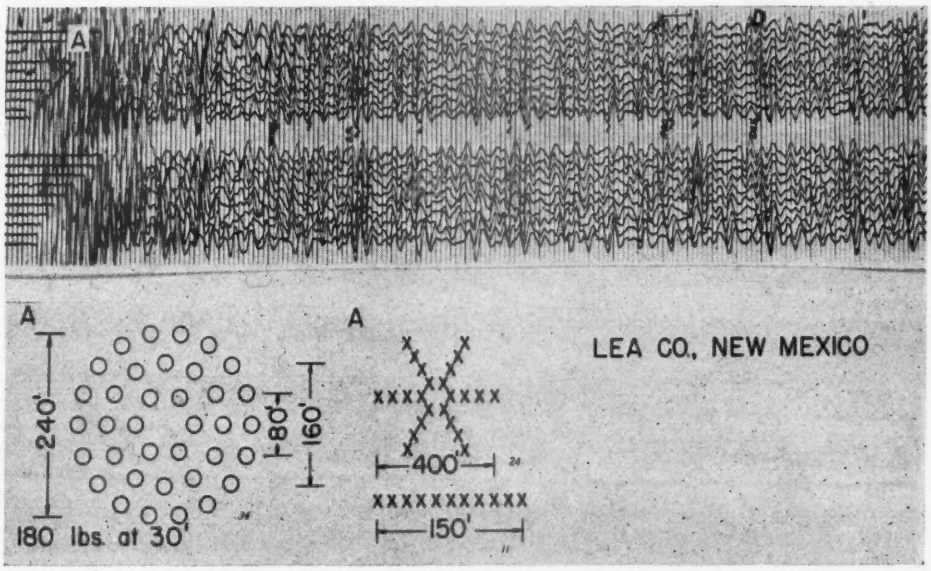

FIG. 6. Record obtained at the same spread location as Figure 5 using a 36-hole shot hole pattern with a total of 180 pounds of powder shot at 30 feet. The upper half of the record uses 24 seismometers per trace in a star-type pattern, and the lower half of the record over the same surface spread uses 11 seismometers per trace. There is no instrumental mixing in either record. "A" is considered Abo depth (Lower Permian), and "D" Devonian depth.

in that region has been attempted first with conventional methods, later with refractions, and now with patterns. Some representative records from this area are shown in Figures 22 and 23.

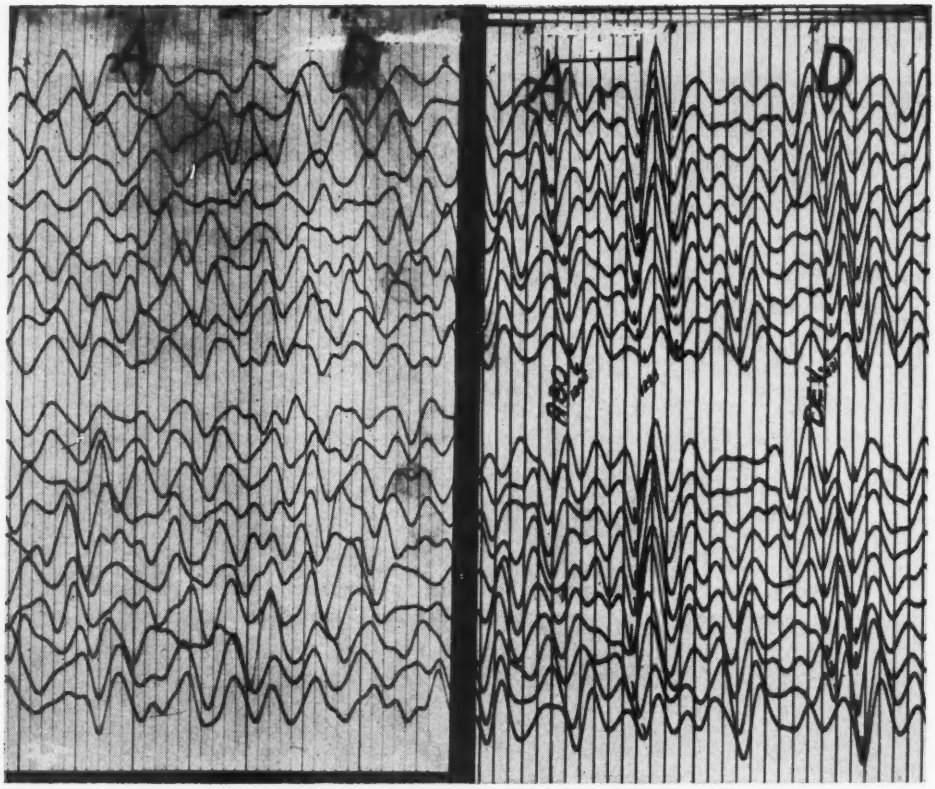

FIG. 7. Enlargement of records shown in Figures 5 and 6, the left-hand record being from a single hole.

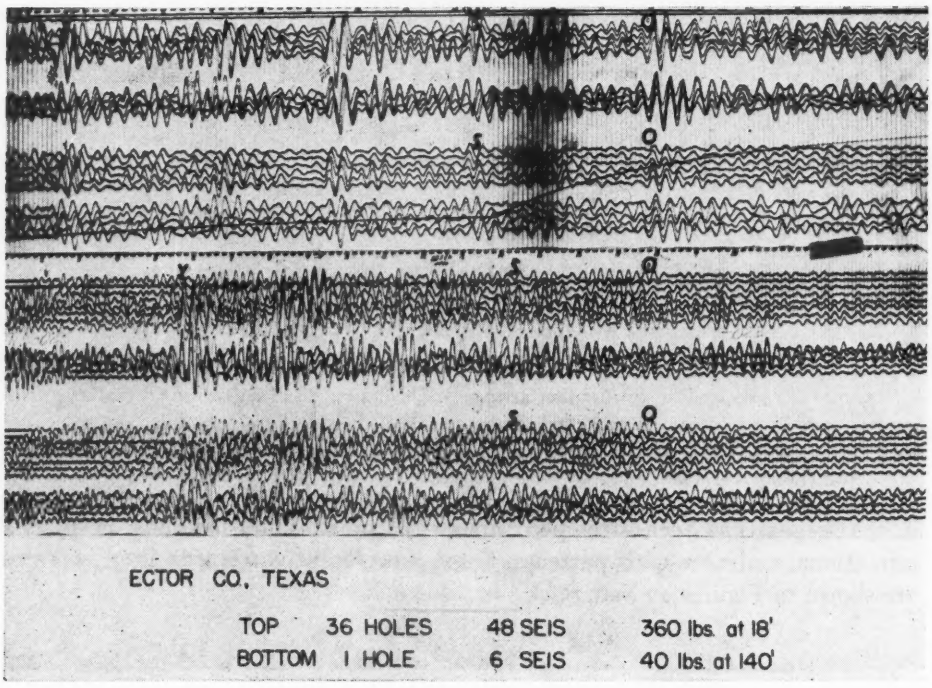

FIG. 8. *(Explanation on facing page)*

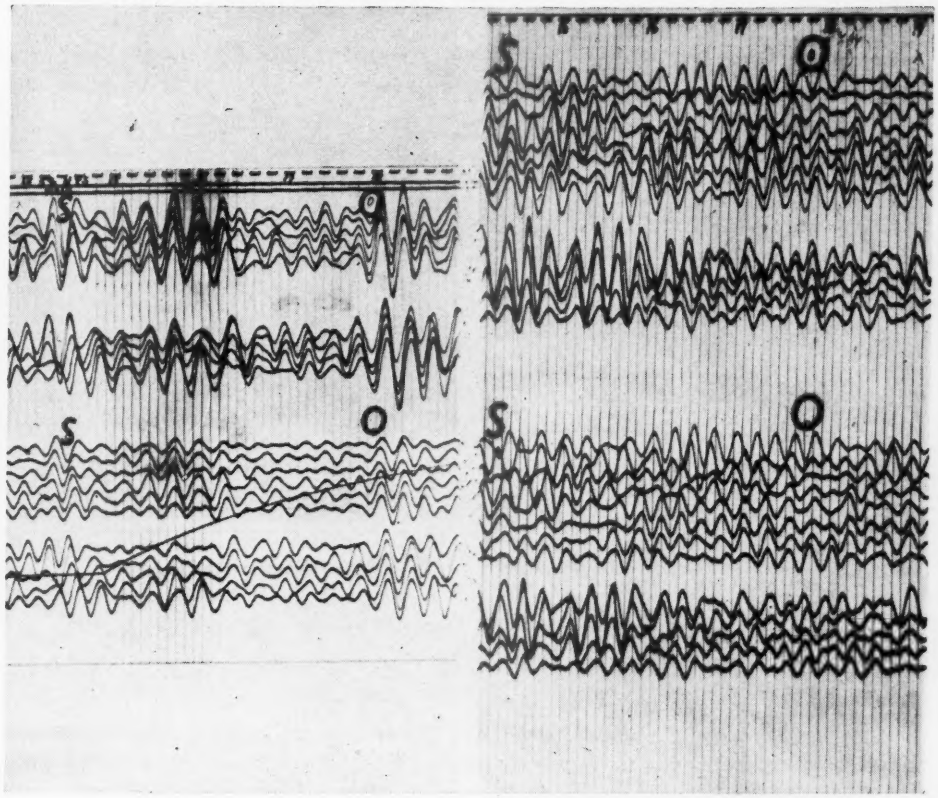

FIG. 9. An enlargement of the Strawn and Ordovician interval of the record in Figure 8, with the 36-hole record on the left.

FIG. 8. 36-hole pattern versus single-hole shooting in Ector County, Texas. Both examples are dually recorded; the upper half of each record is mixed and the lower half unmixed. The top record was obtained with a 36-hole pattern having a diameter of 360 feet and 48 seismometers per trace in a star-type pattern, also with a diameter of 360 feet. Ten pounds was shot simultaneously per 18-foot hole giving a total charge of 360 pounds. The lower record is from a single-hole shot with 40 pounds at 140 feet and from a spread with six seismometers per trace. It should be noted that there is a paper speed difference on these records. The "Y," "S", and "O" are identified as Yates, Strawn, and Ordovician.

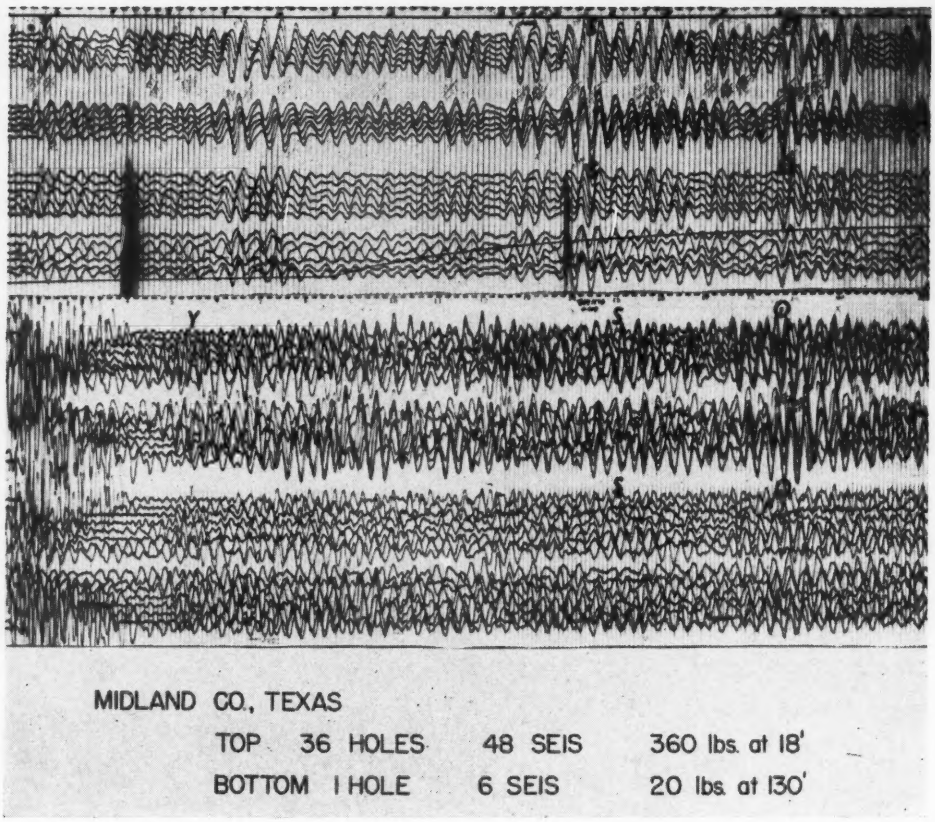

FIG. 10. Comparison of a 36-hole pattern with 48 seismometers per trace versus a single hole with six seismometers per trace, arranged as in Figure 9. Here again there is a paper speed difference. The records are dually recorded, and the Yates, Strawn, and Ordovician are labelled.

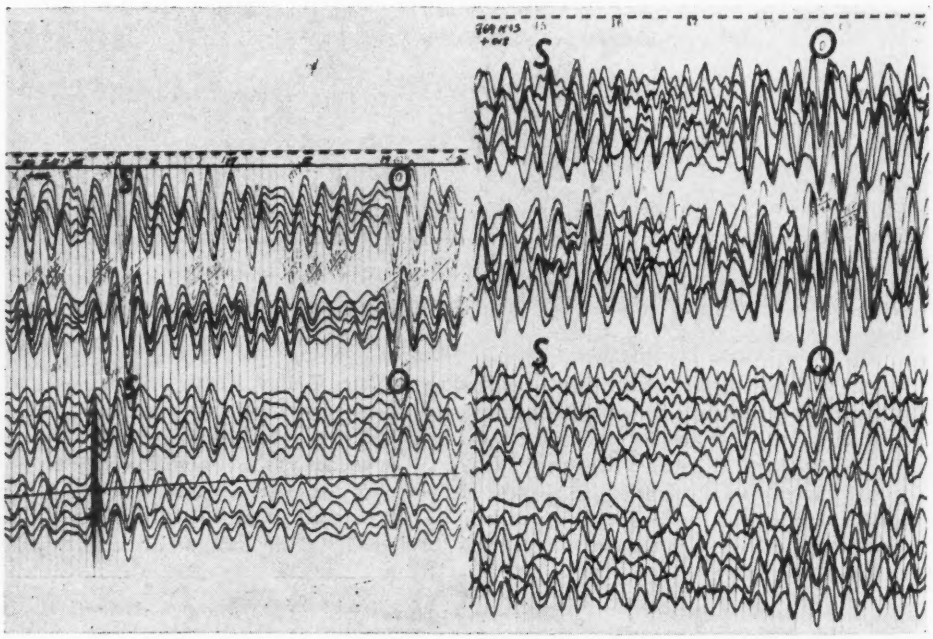

FIG. 11. An enlargement of the Strawn-Ordovician interval of Figure 10; the 36-hole pattern is on the left.

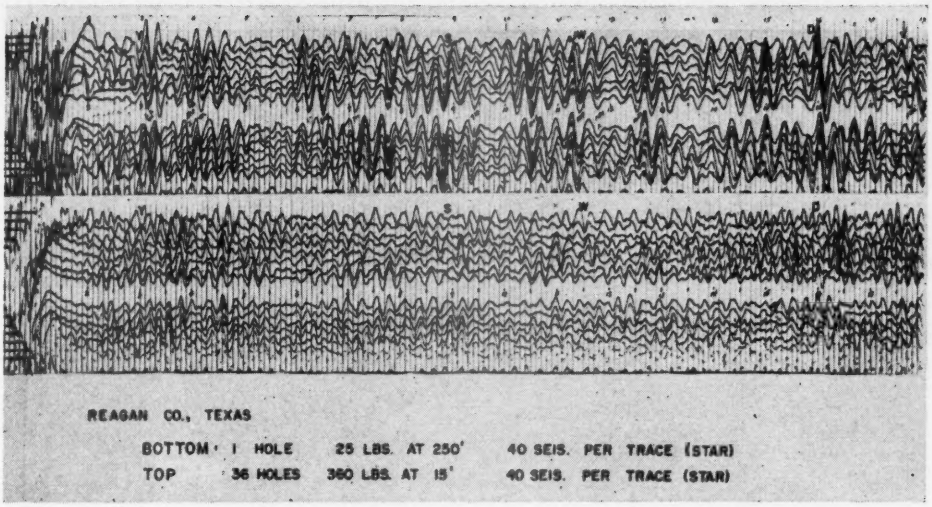

FIG. 12. Record comparisons from Reagan County, Texas, located on the northern tip of the Edwards Plateau. The top record was obtained using a 36-hole pattern 360 feet in diameter with a total of 360 pounds shot at 15 feet. The lower record was obtained from a single shot hole with 25 pounds at 250 feet. The plateau area is so well known for its poor single-hole reflection quality that this record is the only one included in this review. Both records use 40 seismometers per trace in a star pattern and no mixing. "Y", "S", "W", and "D" represent Yates, Spraberry, Wolfcamp, and Devonian respectively.

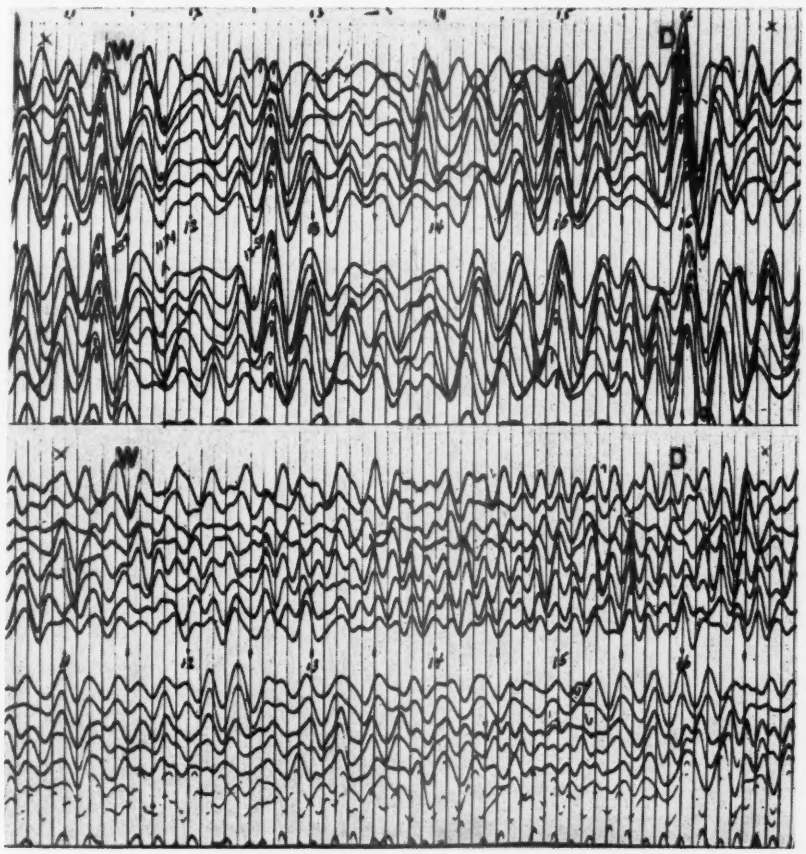

FIG. 13. An enlargement of the Wolfcamp-Devonian sections of the records shown in Figure 12, the upper record being from the 36-hole pattern.

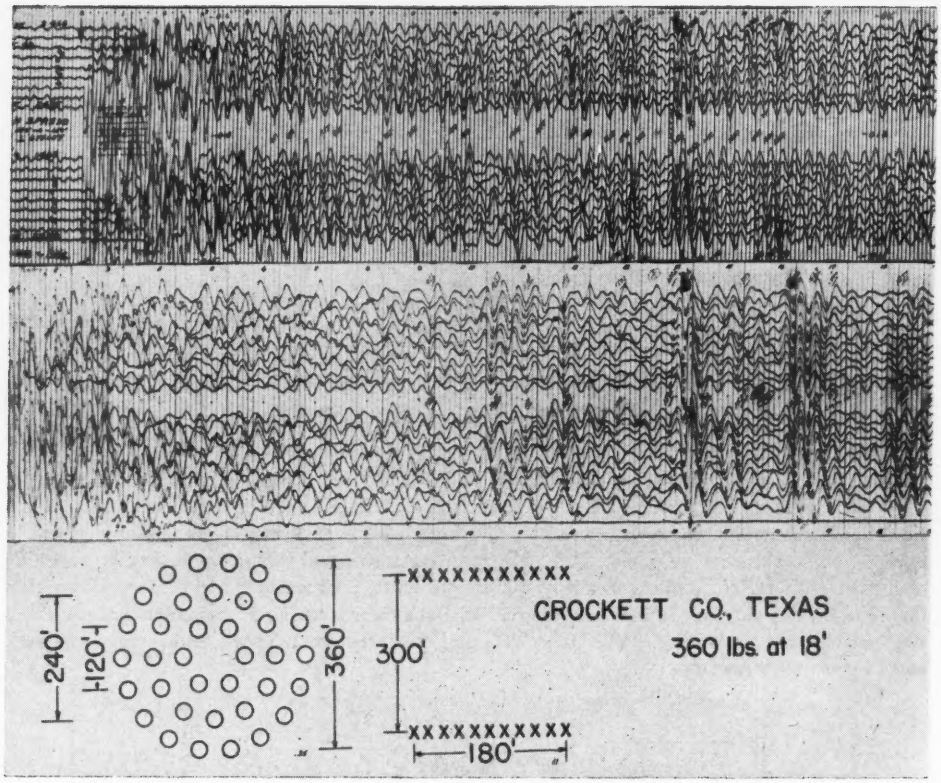

FIG. 14. Two pattern records obtained in Crockett County, Texas, south of Reagan County. Both were obtained using a 36-hole pattern as shown, with 22 seismometers per trace. One trace is shown in the diagram as set up with two parallel cables. There is a timing difference between these two records. "b", at approximately 1.4 seconds, is considered the Ellenburger, and "a" is a rather persistent erratic or unidentified reflection.

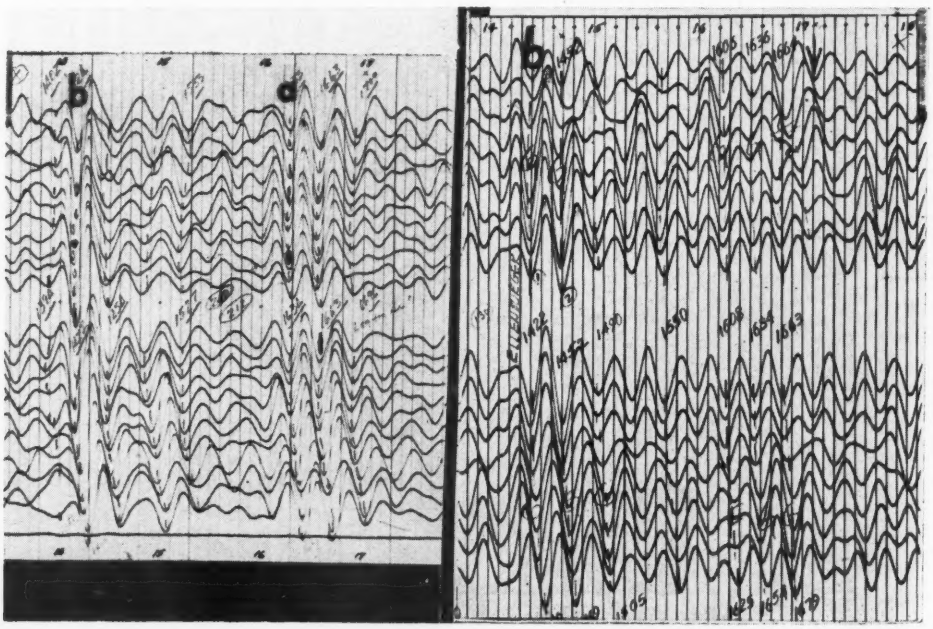

FIG. 15. An enlargement of portions of the records in Figure 14 at Ordovician depth.

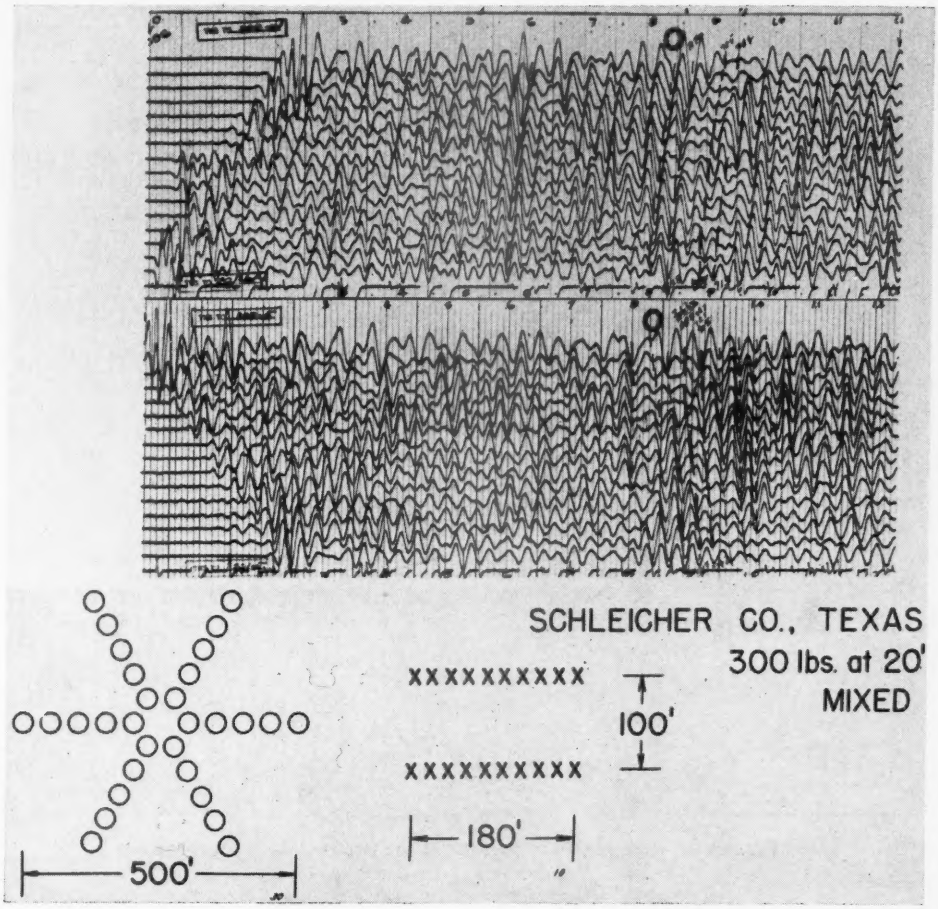

FIG. 16. Two single-ended spreads shot in Schleicher County, Texas with a 30-hole star pattern with 20 seismometers per trace, and mixed. The "O" is approximately Ordovician depth which is considerably shallower than in Crockett County, since the formations are rising rapidly to the east toward the Central Mineral Region.

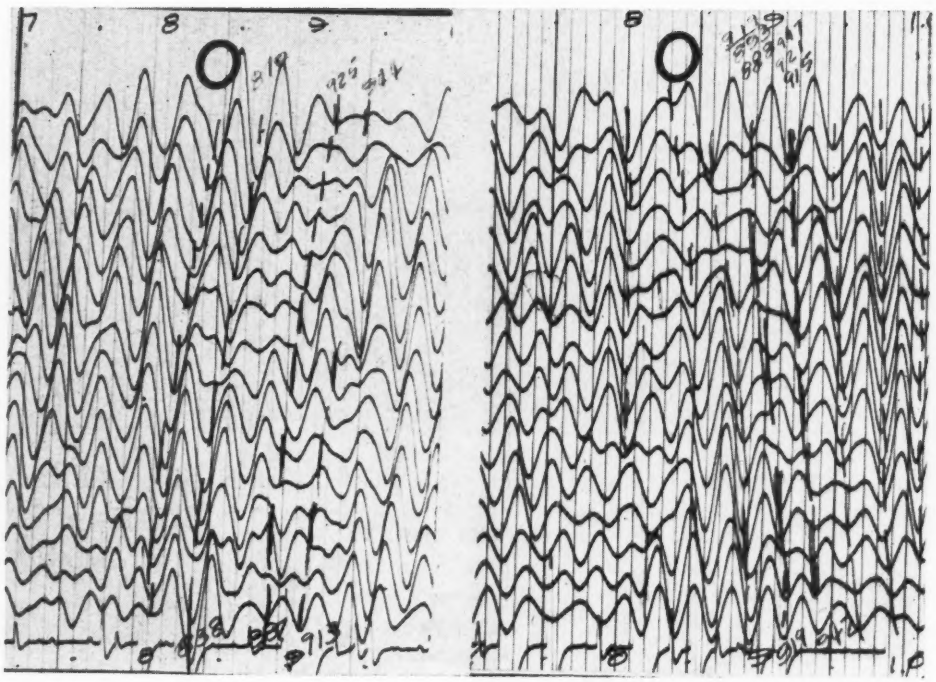

FIG. 17. An enlargement of portions of the two records in Figure 16.

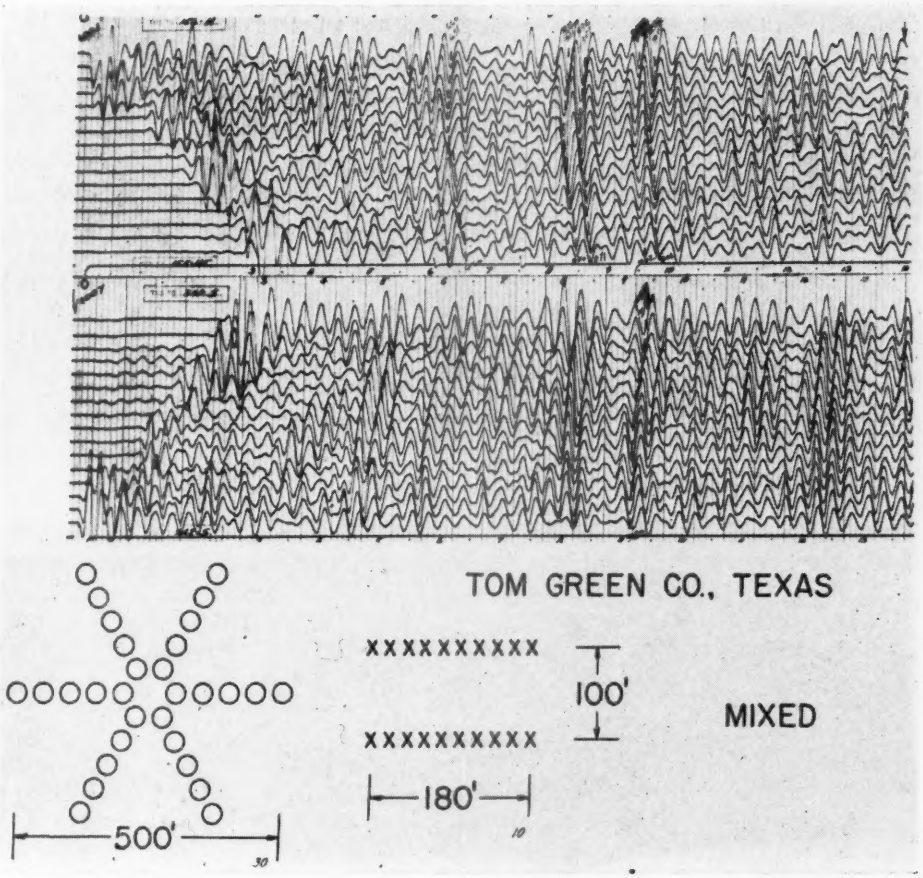

FIG. 18. Two single-ended records shot in Tom Green County, Texas, with a 30-hole star pattern with 20 seismometers per trace and mixed. The "A", at approximately one second, is about Ordovician depth.

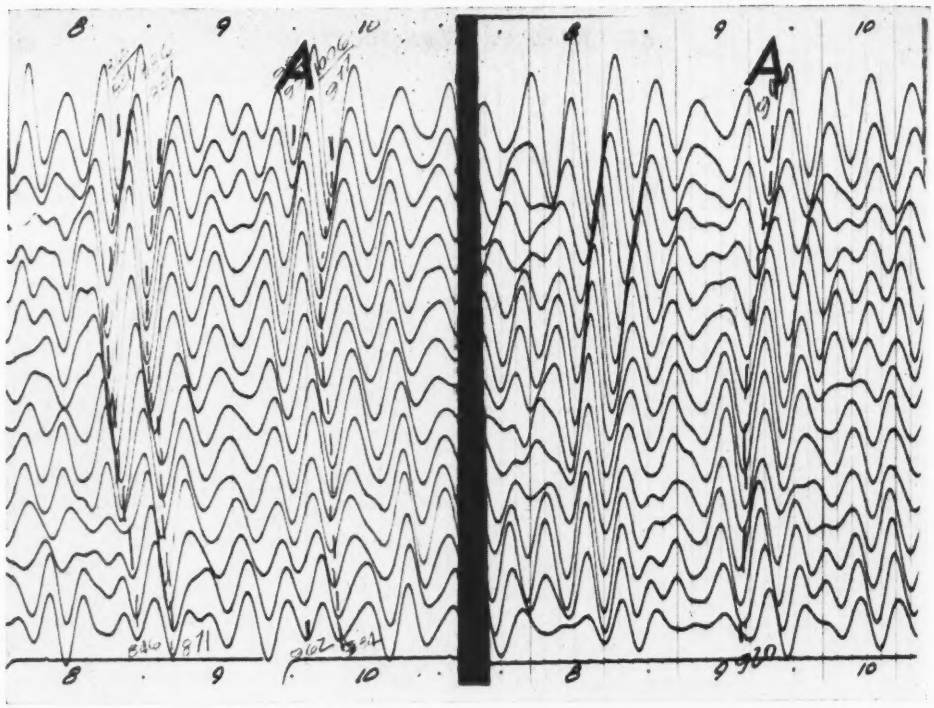

FIG. 19. An enlargement of corresponding portions of the two records in Figure 18.

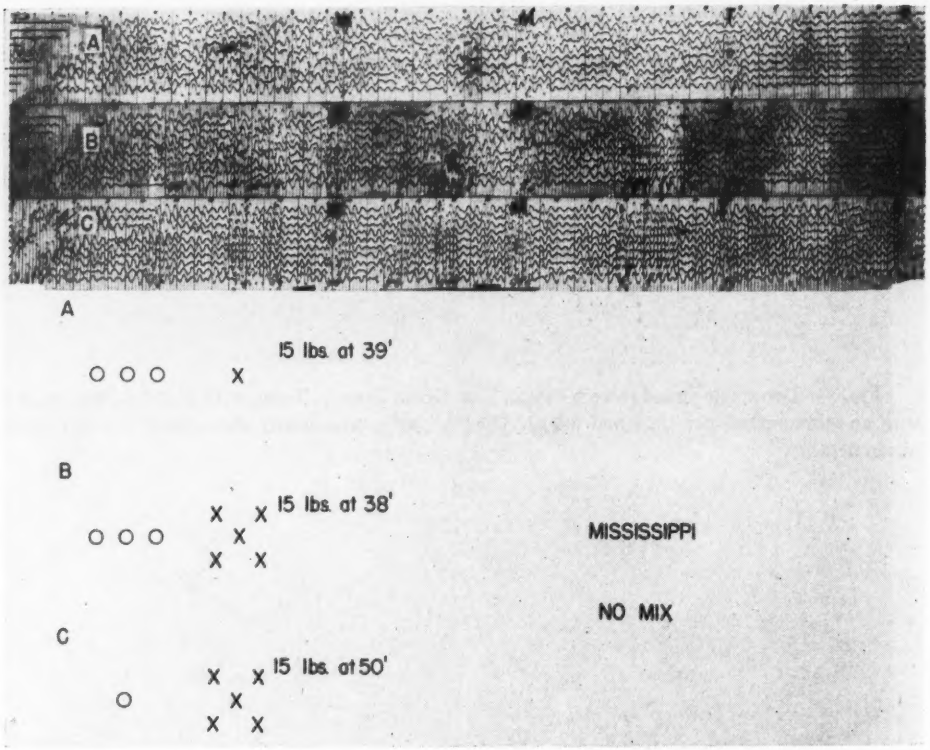

FIG. 20. Comparison of records obtained with three shot-geophone arrangements in Jefferson County, Mississippi. "W" is Wilcox depth, "M" Midway, "T" Tuscaloosa, and "R" Rodessa.

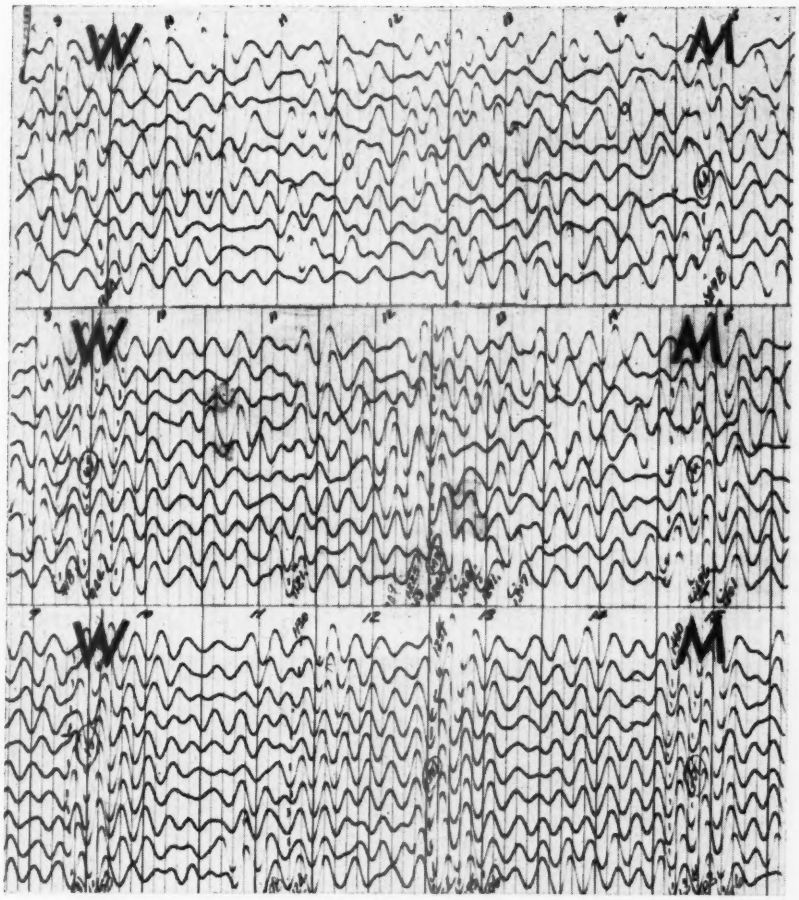

FIG. 21. An enlargement of the Wilcox-Midway portion of Figure 20.

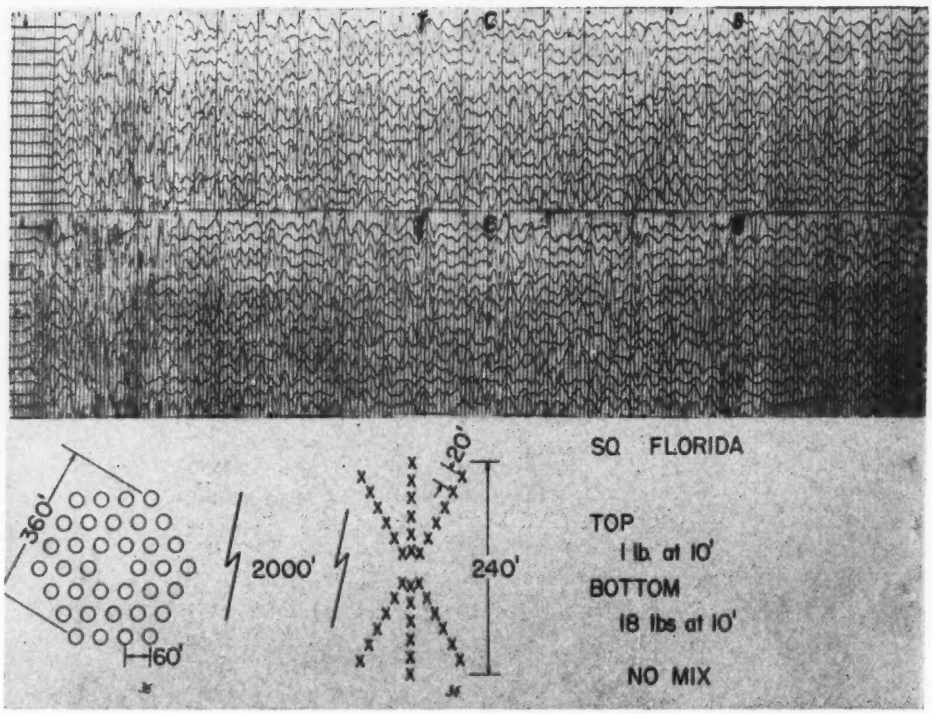

FIG. 22. Two records obtained west of Lake Okeechobee toward the southern end of the Florida peninsula. The surface is a marine shell marl and the subsurface is predominantly limestone. The top record is obtained from a single hole with one pound at 10 feet, and the lower record was obtained using 36 holes as shown. The seismometer arrangement is in a star-type pattern with 36 seismometers per trace and with a right-angle offset of 2,000 feet. The "T" is approximately the base of the Tertiary, "C" is Cretaceous, and "B" is very near the basement rocks.

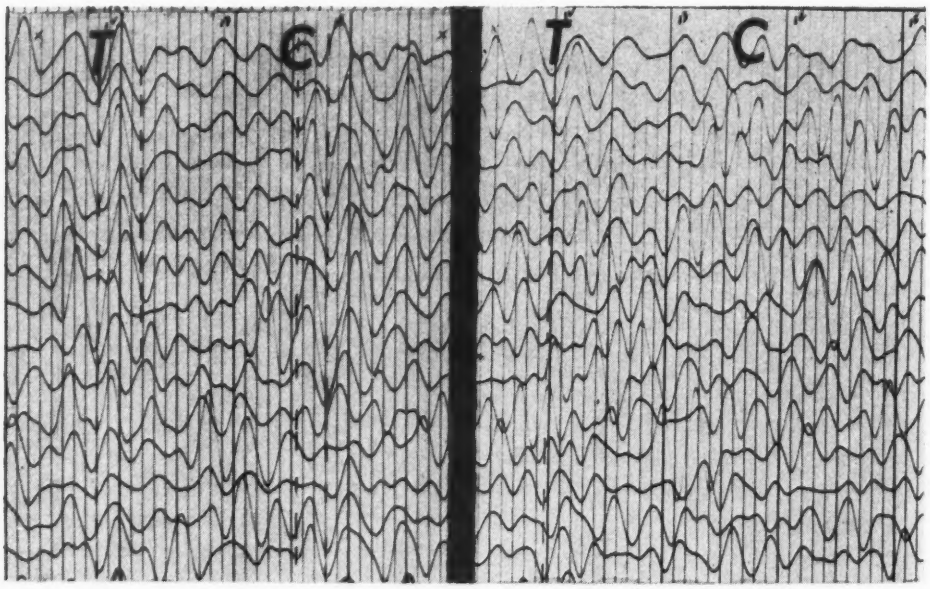

FIG. 23. An enlargement of the Cretaceous interval on the records in Figure 22, the right-hand record being from the single hole.

CONCLUSIONS

1. Patterns of shot holes in conjunction with multiple seismometers do, in many areas, materially improve seismograph reflections.

2. Patterns of shot holes and/or multiple seismometers are not by any means a cure-all. There are still areas of very poor data with a combination of the best techniques in use today.

3. No single pattern of holes or seismometers is unique, either for all areas or for individual areas.

4. Hole depths are critical, as in any seismic technique. In some regions shot holes in patterns apparently are most useful when drilled into the unweathered zone, while in certain other areas this does not appear to be necessary.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to the many oil companies and geophysical contractors who contributed the records for this paper, and to the many geophysicists who have aided in its preparation.

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GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 438–454, 7 FIGS.

A GEOLOGICAL AND GEOPHYSICAL STUDY OF PILOT KNOB (SOUTH), TRAVIS COUNTY, TEXAS*

FREDERICK ROMBERG† AND VIRGIL E. BARNES‡

ABSTRACT

Pilot Knob is an exhumed volcano of Cretaceous age, composed of "serpentinized" pyroclastics and minor amounts of basalt in both intrusive and extrusive masses. The geology of Pilot Knob was re-examined, and gravity and magnetic observations made and interpreted, in order to present a complete picture of the feature itself, its history, its relation to the region and area surrounding it, and the resemblances between it and the serpentine plugs in the neighborhood, to which it is geologically related. Some of these plugs have been discovered by geophysical means, and some so discovered have produced oil; the application of gravity and magnetic data to such discoveries is analyzed.

The extrusive masses are here reported for the first time, and other evidence is given for the age and volcanic nature of Pilot Knob. The observations reveal 1) strong gravity and magnetic anomalies over the central basalt mass, 2) a pattern of weaker anomalies probably caused by flows and dikes and suggesting that Pilot Knob is situated near the intersection of two sets of fractures, and 3) evidence that "serpentinized" pyroclastics show weak magnetic anomalies and (in the local setting) no visible gravity anomalies.

INTRODUCTION

The purpose of this paper is to integrate geologic and geophysical data in order to arrive at a reasonable interpretation of "serpentine plugs,"[1] their origin, and detection where buried. Pilot Knob is a "serpentine plug" exposed by erosion. It differs from the oil-bearing "serpentine plugs" of central Texas only with respect to degree of burial and the presence of basalt. Nothing has been published about the gravitational field of these features, and Pilot Knob, being exposed, offers an excellent opportunity for such a study. The gravity survey described in this paper was conducted to obtain data bearing on this point. The collection of magnetic data was not at first contemplated, as magnetic studies of "serpentine plugs" are already published (Collingwood and Rettger, 1928; Collingwood, 1930; Jenny, 1951); however, when a magnetometer became available two profiles were made.

The gravity observations were made mostly by Romberg; some were made by Melvin Sackrey, including the observations from which gravity profiles *G-G″* and *H-H′* were made (See Fig. 5). The position and elevations of the stations

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‡ Bureau of Economic Geology, The University of Texas, Austin, Texas.

[1] This entire phrase, "serpentine plug," is a misnomer but is retained in this paper because of its widespread usage among oil men. These features are actually piles of volcanic debris and not plugs in the sense of volcanic necks. The so-called "serpentine" is not actually serpentine but is nontronite; this identification was made by Dr. E. J. Weiss, Ceramic Engineering Department, The University of Texas, using X-ray diffraction methods.

were determined by Barnes assisted by T. R. Walker and H. L. Ellinwood. The gravity data were reduced by the various members of the party. The magnetic data were obtained, and the reductions made, by W. A. Anderson, who used a Schmidt-type vertical magnetometer built by the American Askania Corporation. The scale constant at the time of the survey was about 22.3 gammas per scale division, and the usual corrections were applied to each observation. Romberg and Barnes are responsible for interpreting the data and for the conclusions.

The writers are very much indebted to the firm of LaCoste and Romberg for the loan of a gravity meter and calculator; to the Arkansas Fuel Oil Company, through the intercession of James Rogers, for the use of a magnetometer; to the Frost Geophysical Corporation for the loan of apparatus to determine magnetic susceptibility; to W. R. Varnell, Jr. for making the magnetic susceptibility measurements; to Dr. L. L. Nettleton for help in interpretation of magnetic data; to the Carnell Oil Company for gravity data in the vicinity of Manda and Lund oil fields; and to the Petty Geophysical Company for calibraing the magnetometer before and after the survey. Without this willing cooperation it would have been impossible to gather the geophysical data.

GEOLOGY

More than 60 years ago Hill (1890) recognized that Pilot Knob is of volcanic origin and that it is Cretaceous in age. The sequence of geologic events that Hill proposed is accepted with very little modification by the authors of this paper.

Surface Geology

Hill describes Pilot Knob as a high area of basalt, the neck of an ancient volcano, surrounded by a low flat area of soft, yellow, exfoliating material, some of which is undoubtedly the product of basaltic decomposition while in other places it resembles volcanic ash. Austin chalk crops out peripherally to the flat area, dips away from Pilot Knob, and forms an inward-facing scarp. The Austin chalk rests on the volcanic debris and throughout its whole extent is crenulated into gently waving undulations. Hill mentions the presence in the volcanic material of oysters preserved by the falling debris, showing that the volcano was definitely on the sea bottom. Alternations of chalk and volcanic materials are also mentioned, showing that sedimentation continued during the period of volcanism. Deposits of this type crop out for distances up to 4 or 5 miles from Pilot Knob. Hill also states that Pilot Knob was covered by sediments of Taylor and later age, and that the Balcones faulting occurred at a still later date. Figure 1 is modified from a map by Hill and Vaughan (1902) showing the distribution of igneous rock in the Austin area. Hill's observations are supported by the evidence presented in Appendix A: Petrographic and Historical Geology (see pp. 450–452).

Subsurface Geology

The geologic cross section *A-A′* (Fig. 2) was constructed from data in the files of the Bureau of Economic Geology. Data from the following wells were used:

Ewell Nalle et al. No. 1 D. Collins; Holmstrom and Caffey No. 1 Collins; Marshburn and Bybee No. 1 James Ross; and Kopel and Ginsburg No. 1 Harry Mayne. These wells are not on the line of section *A-A'*, but on the assumption that Pilot Knob is a cone the data from the wells are projected into the line of section. The shapes of the basalt masses are hypothetical.

Shape of Basalt Masses

The geologic interpretation of the shape of the basalt masses in Pilot Knob is based on observations of basalt columns along the western and southern borders of the knob. Basalt columns form perpendicularly to the cooling surfaces; thus the orientation of a tabular basalt mass can be determined from observation of the columns. The basalt is mostly in sheets dipping about 30 degrees toward the center of the volcano. Two sheets not connected at the surface with the main group of sheets are present on the southwestern side of the knob. These, while not dipping toward the center of the volcano, strike toward the main group of sheets and are probably connected with them under the surface. Dikes which are well exposed dip from 80 to 90 degrees. Some sharp symmetrical ridges of basalt boulders are also interpreted as dikes.

The data thus suggest that the central igneous mass is composite, being formed by sheets of molten basalt intruded upward and outward into the cone of volcanic debris, where they solidified. As the cone grew larger the sheets were intruded at successively higher levels and eventually broke through the side of the cone to form flows. This interpretation is to a large extent supported by the gravity and magnetic data.

GEOPHYSICAL DATA

Gravity Observations

The gravity observations were corrected in the usual manner, and a contour map (Fig. 3) was drawn from them. The expected error in the observations is less than one-tenth milligal. No terrain corrections were made since the observed anomalies are large enough that errors due to terrain will not affect the conclusions. The map indicates an apparent uniform regional gradient of 0.58 mg/mile, dipping west-southwest. A second gravity map was drawn with the regional gradient subtracted (Fig. 4). Comparison of the maps shows that the main features are not modified, though the minor anomalies are better defined. Cross-sections of gravity are shown in relation to the main geologic features (*A-A'*, *B-B'*, *C-C'*, Fig. 2; and *G-G''*, *G-G'*, *H-H'*, Fig. 5).

The most notable feature of the gravity map is the strong maximum produced by Pilot Knob. Other dominant features are the lesser maxima surrounding the knob, a northeast-southwest trending high axis plunging to the southwest, and a parallel trough southeast of it. Pilot Knob is at the crest of the high axis.

Magnetic Observations

The magnetic observations are presented as profiles rather than as a complete map. A map was drawn showing the locations of the magnetic profiles and the areas of positive and negative anomaly (Fig. 6). Cross sections of these profiles were drawn, and these are shown in relation to the central basalt mass and to the associated gravity cross section in Figure 7. Profile *E-E'* clearly shows a large positive anomaly over the central mass, surrounded by a zone of negative anomaly. The subsidiary positive gravity anomalies correspond to positive magnetic anomalies.

GEOPHYSICAL INTERPRETATION

Central Basalt Mass

The geologic map (Fig. 1) shows the extent of the basalt outcrop on Pilot Knob; this area of outcrop is roughly circular and about 2,500 feet in diameter. Comparing the size of the gravity anomaly with the dimensions of the outcrop permits certain deductions to be made regarding the subsurface configuration of the basalt.

1) If the area shown were the top of a vertical cylinder of solid basalt extending to great depth it would give rise to an anomaly of about 16 mg. (The density data from which this computation can be made are given in the Appendix.) The anomaly actually observed, about 4 mg, accounts for such a vertical cylinder half a mile in diameter but only about 400 feet deep. It is, of course, geologically unlikely that there is no basalt deeper than 400 feet; such intrusions as Pilot Knob usually have necks underneath them extending to an unknown depth. This suggests that the basalt mass may be thin at the edge and may extend to a greater depth than 400 feet in the middle.

2) If the bulk of the basalt were in the form of a neck, with a small proportion of the total mass elsewhere, the neck would be 650 feet in diameter.

3) If the basalt were concentrated in the form of an inverted cone, with a comparatively small neck or cylinder below it, the half-angle of the cone's apex would be computed at 53 degrees. This third case is also a limiting one, of course, and just as unlikely geologically as the other two.

In summation, it is clear that there should be lighter material than basalt underneath the area of the outcrop; this is suggested by the geological interpretation.

The magnetic anomaly associated with the central mass has a measured range of 4,000 gammas plus an unknown additional amount; three observations were attempted which were beyond the limits of the instrument as calibrated. The central part of profile *E-E'* (Fig. 7), over the main basalt mass, exhibits a magnetic anomaly similar to that which would be observed over a short vertical cylinder. (Nettleton, 1940, p. 216.) The upper boundary of such a cylinder, acting

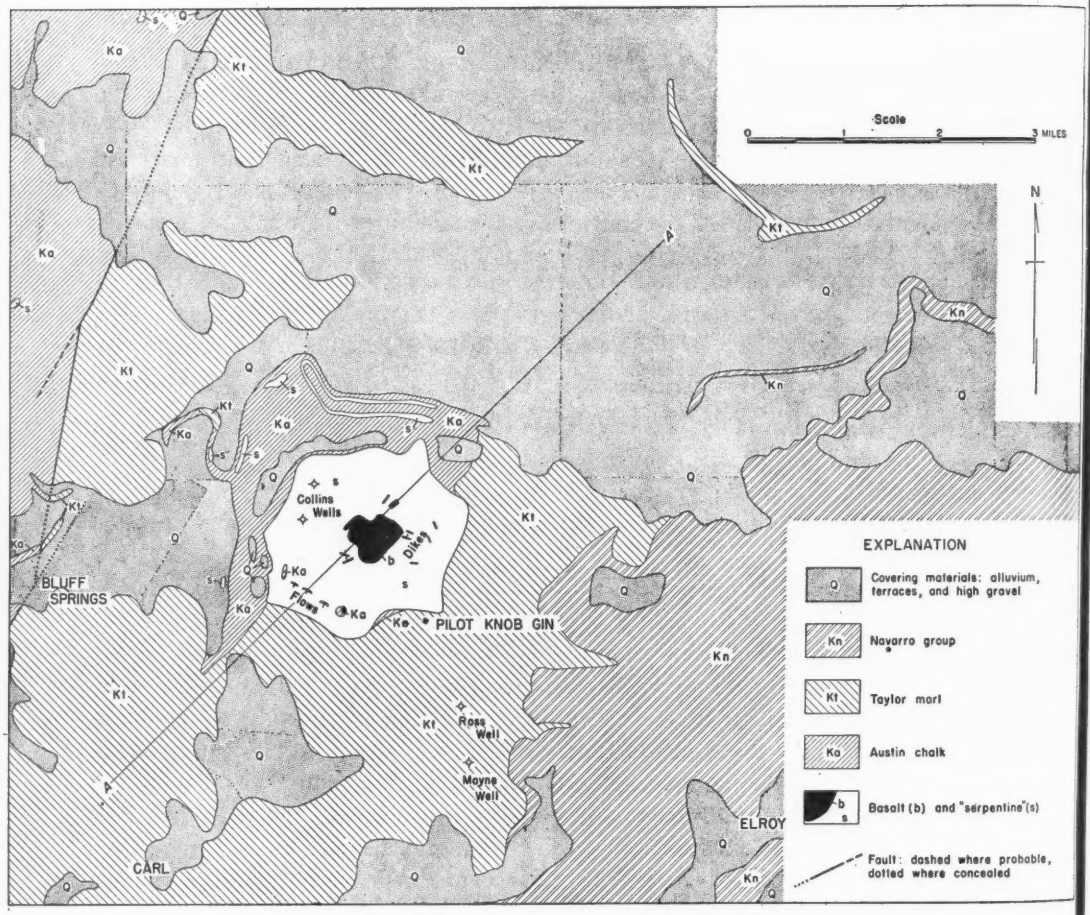

FIG. 1. Geologic map of an area in vicinity of Pilot Knob (South), Travis County, Texas. (Modified from Hill and Vaughan.)

as a disc of positive poles close to the surface of the ground, would create a sharp positive anomaly. The lower boundary, some distance below the surface, would yield a less sharp negative anomaly. The sum of these two anomalies makes a *W*-shaped curve whose central peak is high above the vertical axis and whose side troughs or valleys are a less distance below it. The observed anomaly is clearly of this type, although its south side is somewhat sharper than the north, and therefore perhaps more closely representative of the central mass. Computations based on the solid angle chart given by Nettleton (1942, p. 302) show that the observed data, though not complete enough to give a quantitative answer, are consistent with the hypothesis of a vertical cylinder of magnetic material with its lower boundary at a depth equal to or somewhat greater than its radius.

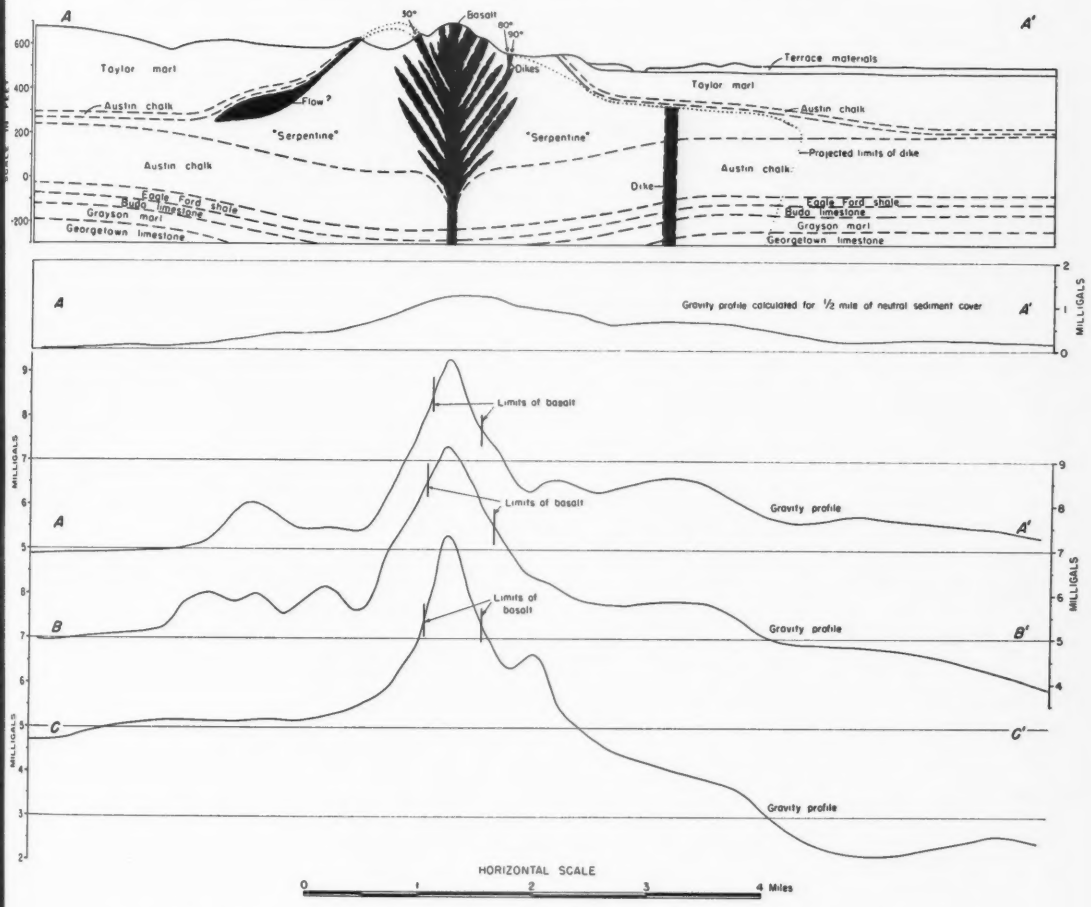

FIG. 2. Geologic cross section and gravity profiles, Pilot Knob (South), Travis County, Texas.

Outlying Basalt Masses

A second conspicuous feature of the gravity map is the group of smaller positive anomalies irregularly grouped around the main mass. These can be seen in profile in Figures 2 and 5, and are thought to be caused by basalt in the form of flows, possibly also sills and dikes. This interpretation is shown in diagrammatic form in profile *A-A'* (Fig. 2). It is supported by the fact that the gravity anomalies are associated with positive magnetic anomalies and with the outcrops of basalt.

The most important group of basalt outcrops outside the area of the main mass is a row of crescent-like asymmetrical basalt ridges south of the Knob, having their scarp sides toward the volcano and coinciding in location with some

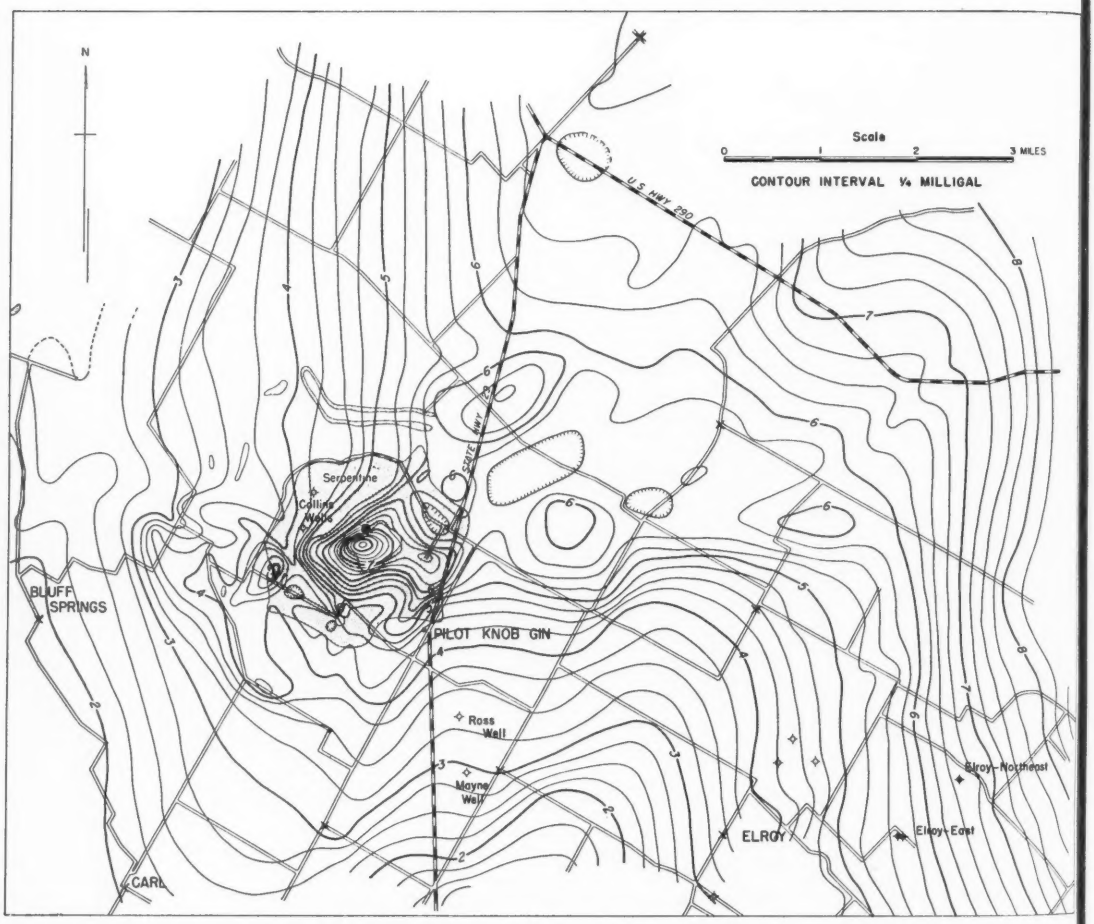

FIG. 3. Gravity map without regional gradient removed, Pilot Knob (South), Travis County, Texas.

of the positive gravity anomalies. Profiles *G-G″*, *G′-G″*, and *H-H′* (Fig. 5) show the gravity variation as one crosses these features. The ridges are interpreted as being sheets of igneous rock sloping away from the volcano; if this is correct they are probably flows, or less probably sills. The basalt in the sheets is petrographically similar to that forming Pilot Knob, and the density contrast (see Appendix B) can be used to show that the anomalies of profile *G′-G″* could be produced by flows 20 to 30 feet thick.

Magnetic and gravity profiles *E-E′* (Fig. 7) show a sharp positive anomaly as they cross a basalt outcrop and a broader one a little farther south. A hand-dug well south of this outcrop passed through 17 feet of basalt dipping six and one-half degrees south. The gravity anomaly over the outcrop is small and the magnetic one large, indicating a shallow mass; the gravity anomaly farther south is large and the magnetic anomaly small, indicating a large deep mass. This is in-

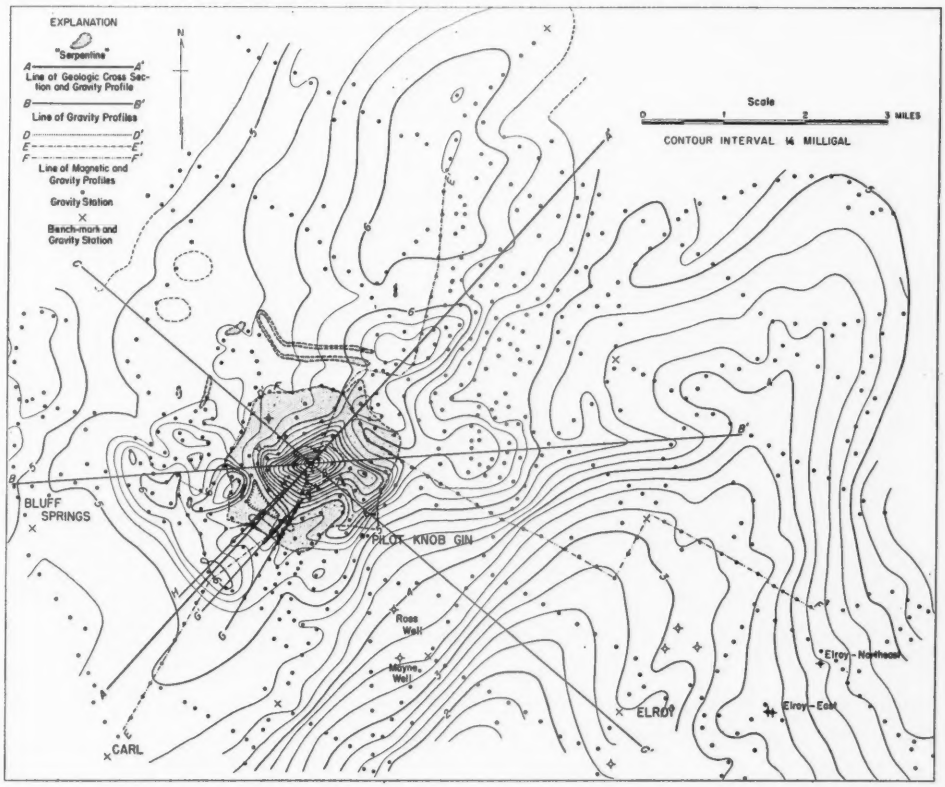

FIG. 4. Gravity map with regional gradient removed, Pilot Knob (South), Travis County, Texas.

terpreted as being a flow southward from the volcano, which formed a pond at its southern end (profile *A-A'*, Fig. 2).

Magnetic and gravity profiles *F-F'* (Fig. 7) both show positive anomalies at magnetic station 45, northeast of the main mass; there is a basalt outcrop in the neighborhood which might be a flow or a dike. Profile *D-D'* (Fig. 7) shows a coincidence of positive gravity and magnetic anomalies; this could be caused by an inclined intrusive. Thus, in general, positive magnetic anomalies, positive gravity anomalies, and basalt outcrops occur together.

On the gravity map, the Pilot Knob anomaly and the minor anomalies surrounding it are arranged in the form of a cross, with one set of anomalies aligned in an east-west direction and the other in a north-northeast—south-southwest direction. The latter line, instead of passing through the center of Pilot Knob, appears to include the eastern extension of the main knob anomaly. Such alignments suggest that Pilot Knob is situated on a main east-west fracture near a less prominent cross-fracture, and that masses of basalt of various sizes along the fractures are responsible for the anomalies. This interpretation does not account

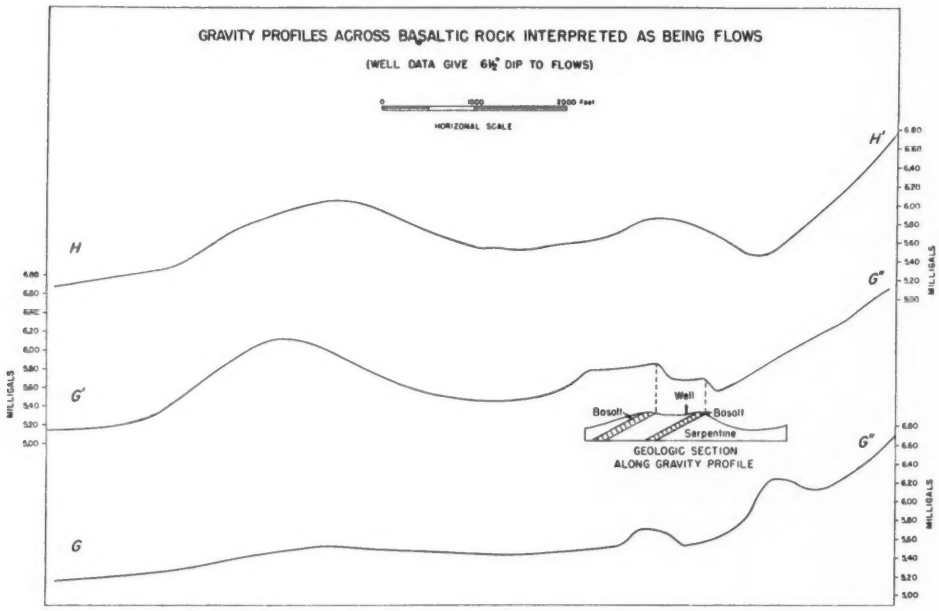

FIG. 5. Gravity profiles across basalt flows, Pilot Knob (South), Travis County, Texas.

for all the subsidiary anomalies; the evidence suggesting that some of these are flows has been discussed above.

"Serpentine"

The magnetic data, though limited, indicate that the outcropping "serpentinized" pyroclastics are mostly in an area of negative anomalies. This requires explanation since the "serpentinized" pyroclastics are derived from basalt and should behave in a similar way magnetically. Thin sections of the "serpentine" were examined and found to contain magnetite, as expected, though considerably less than did the basalt; most of the finer particles of magnetite seem to have disappeared during "serpentinization." Enough magnetite remains, however, to make the "serpentine" much more magnetic than the surrounding sediments.

The following explanation is proposed for the negative anomaly exhibited by the "serpentine": The original basalt has strong polarity in the direction of the earth's field, presumably developed during its solidification. The pyroclastic material came to rest with random magnetic orientation, and since it was then solid there was little tendency for it to re-orient itself into polarity. The much stronger negative polarity induced (at a short distance) by the negative pole of the neighboring basalt would thus account for the negative magnetic anomaly over the "serpentine."

The layer of "serpentinized" pyroclastic material extends for a distance of

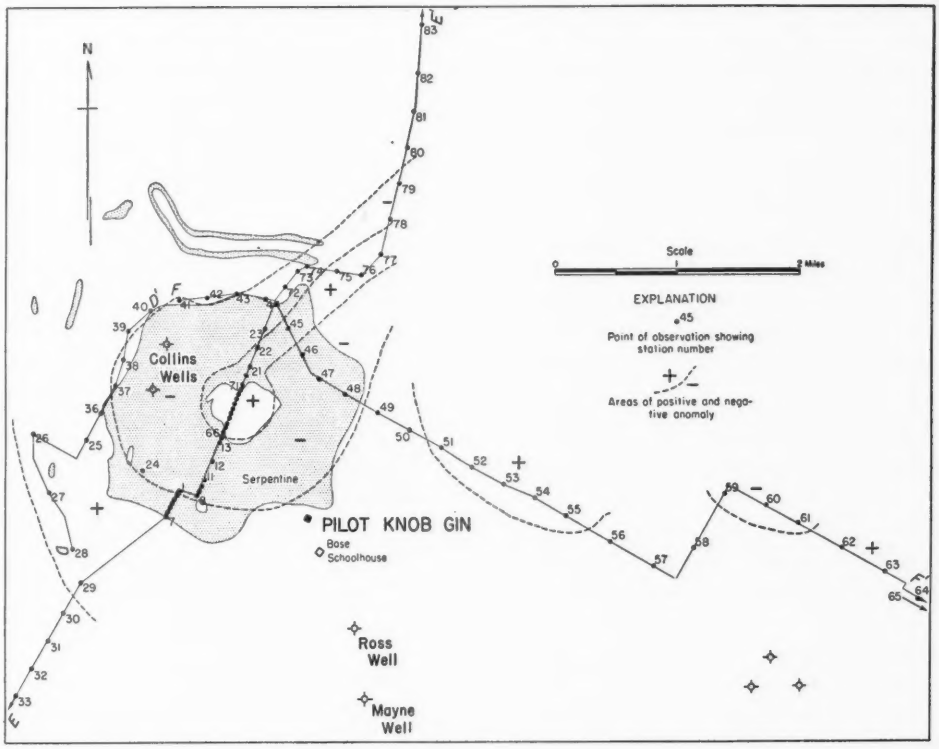

FIG. 6. Magnetic map, Pilot Knob (South), Travis County, Texas.

several miles from Pilot Knob and has a polarity which, although weak, is still strong enough to produce an irregular magnetic profile. It seems likely that this irregularity will be caused by variations in the thickness of the pyroclastics and in its depth, due to structure and topographic relief.

Enough magnetic data have been obtained to show that basalt gives strong anomalies and "serpentinized" pyroclastics give weak ones. An anomaly such as that mapped in the Yoast field by Collingwood (1930) is so slight that one strongly suspects the rock causing the anomaly to be "serpentinized" pyroclastics and that intrusive or extrusive basalt is not present. The Elroy-East anomaly (Jenny, 1951) is considerably stronger and may represent "serpentine" derived in part from non-pyroclastic basalt.

Regional Effects

A large-scale feature of the gravity map is a broad high axis plunging to the southwest, at the crest of which Pilot Knob is situated. This anomaly tends to close at its northeastern end and can thus be thought of as a broad, low positive anomaly some six miles wide and nine miles long. The anomaly might be related to density contrasts in the structurally complex Ouachita facies, which at Pilot

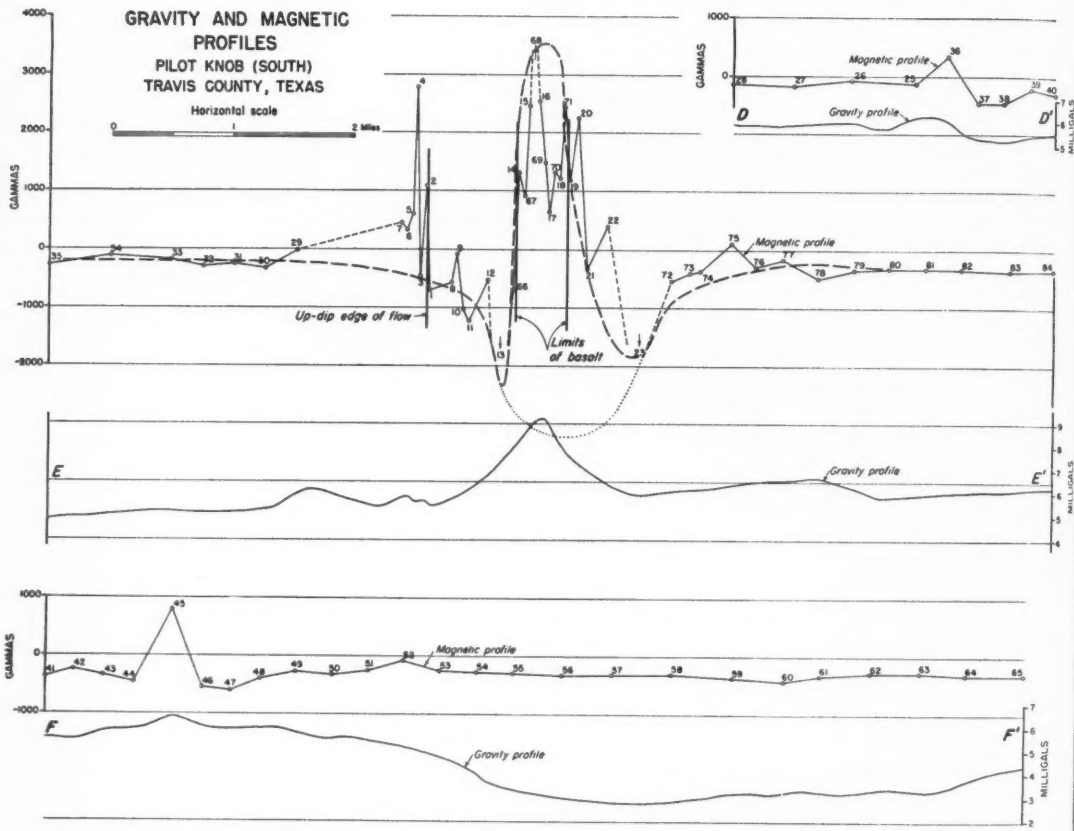

FIG. 7. Gravity and magnetic profiles, Pilot Knob (South), Travis County, Texas.

Knob should be half a mile deep and several miles in thickness. The anomaly might also be caused by a basalt body which could be a sill half a mile deep, 75 feet thick, and some five by eight miles in extent; it could, alternatively, be a compact body three miles deep, three miles long, and two-thirds of a mile in diameter; or it could be anything in between.

The regional gravity map of the Gulf Coast published by Nettleton (1949, Fig. 1) shows a negative anomaly in the position of the Ouachita belt of folding and thrusting. This anomaly varies in magnitude along the belt; there is a low point in eastern Coryell County and another one in the Comal-Hays County area, and these are separated by a saddle in Williamson County. Pilot Knob is situated south of the crest of this saddle. The apparent regional gradient referred to under *Gravity Observations* can be explained on the basis of this picture. A map published by Lonsdale (1927, p. 1, Plate 1) shows that the igneous masses of the Balcones belt are grouped in well-defined areas. The gravity saddle in Williamson County may thus be caused by a large mass of basalt, the reservoir

for the outcropping and near-surface igneous rock, which partly counteracts the negative anomaly produced by the Ouachita facies. The large area without igneous rocks centering about New Braunfels is near the low point of the negative anomaly south of the saddle. It is interesting that Woollard (1948, p. 316) found a similar negative anomaly for the thrust zone of the Appalachians.

Magnetic anomalies in sedimentary terrain devoid of igneous rock are usually attributed to variations in the magnetic properties of the "basement" rocks (Nettleton, 1940, p. 220). The Ouachita facies, directly beneatch the Cretaceous, is a thick sequence of structurally complex sediments exhibiting in this area a very low degree of metamorphism. It might be possible for some polarity to develop during such metamorphism, and this should be kept in mind when interpreting magnetic data in the area. For instance, on the eastern end of the magnetic observations, there is a negative anomaly (stations 59–61, Fig. 6) followed by a smaller positive anomaly (stations 62–63). These may be caused by a fault upthrown to the east but could also be attributed to variations in the magnetic properties of the Ouachita facies.

The pre-Cambrian basement should be at a depth of several miles, and any effect from variations in its magnetic properties should be reflected at the surface only in broad regional features. There is a slight indication of a regional gradient rising to the northeast in the area covered.

OIL EXPLORATION AND PRODUCTION

Pilot Knob

Any oil that may have been present at Pilot Knob would have escaped by now unless prevented from doing so by some barrier. It is barely possible that conditions at the flow fronts are such that oil may have accumulated there, due to a combination of high porosity at the flow fronts and low permeability up dip. However, if Pilot Knob were buried by the overlying Taylor marl, it would make an excellent reservoir for the accumulation of petroleum, provided the "serpentine" were porous enough. Figure 2 shows a hypothetical gravity profile (*A-A'*) which demonstrates that Pilot Knob would be easily discoverable by gravity if it were under half a mile of sediments. In such a case it would obviously give a large magnetic anomaly also.

Other Structures Containing "Serpentine"

Considerable oil has been produced from buried masses of "serpentinized" rock in counties adjacent to Travis County (Sellards, 1932, p. 751–768). An area including some of the known fields was surveyed with an aerial magnetometer (Jenny, 1951). Anomalies were observed on the old fields and new anomalies were found. After these were examined with a ground magnetometer six of them were drilled, and five out of six produced oil. It is thus clear that magnetic exploration is an effective method of looking for "serpentine plugs." The story is different for gravity; no gravity anomaly was observed near the Elroy field in the south-

eastern portion of the area mapped, and a gravity survey by the Carnell Oil Company failed to show any significant anomalies connected with either the Manda or Lund fields in eastern Travis County. This is probably due to the absence of shallow basalt; so far as can be ascertained no unaltered igneous rock has been drilled into in any of the "serpentine" oil fields. Some of the "serpentine" in them may be derived from intrusive and non-pyroclastic extrusive rock. However, most of the igneous rock appears to be "serpentinized" pyroclastics, probably originally in the form of cinder cones. Such cones, being of loose material and standing well above the surrounding sea bottom, should be reworked and interfingered with subsequently deposited strata. Some of the Taylor-age "serpentine" may be of this type.

APPENDIX A

PETROGRAPHY AND HISTORICAL GEOLOGY

Early petrographic work in the area was done by Kemp (1890, p. 292–294) who identified the basalt as a nepheline-basalt composed of small olivine crystals and much smaller prismatic augite crystals scattered through a groundmass. The groundmass is a dark glassy material in some specimens; in others it is a half-opaque whitish mass which gives a test for nepheline. The rock is classified as limburgite. Lonsdale (1927, p. 35–39) later noted that nepheline and glass are rare and that the greater part of the rock is a fine groundmass of augite laths and magnetite grains in which are held numerous larger crystals of olivine and a few of augite. Recent petrographic work, plus new geologic evidence from wells and artificial cuts, encourages us to list the evidence bearing on the geologic history.

1) The dating of the igneous rocks along the Balcones fault zone was originally based on the belief that they were of about the same age, and as some of the rocks in the western part of the province intrude rocks of latest Cretaceous age they were placed as probably early Tertiary. However, these rocks, as well as the faults of the Balcones system, coincide with the Ouachita geosyncline, and it now seems likely that both the igneous rocks and the faults are in some manner related to the geosyncline. The igneous rocks may actually be from local melting of sediments in the geosyncline, and each mass or local group of basalt masses could have formed at a different time. Inspection of the available chemical analyses shows that there is a wide variation in chemical composition. Such a variation might be easier to explain by fusion of heterogeneous sediments than by magmatic differentiation.

The basalt masses were examined in the field, and thin sections of both pyroclastic and basaltic rocks were studied. The pyroclastic rocks are all "serpentinized," but in thin section the original texture can easily be distinguished. The pyroclastics do not appear to differ from the basalt except for their alteration, fragmental nature, vesicularity, and lesser content of magnetite. With one exception the pyroclastics are texturally, and apparently mineralogically, similar

to the basalt. The one exception is a "serpentinized" mass several inches in diameter embedded in well-bedded pyroclastics and interpreted as having been a piece of solidified basalt torn from the throat of the volcano and thrown out with the finer material. (This rock contains an abundance of unmistakable melilite pseudomorphs, whereas none were seen in any of the basalts or in any of the rest of the pyroclastics.)

The above observations encourage the belief that the igneous activity at Pilot Knob is of one general period, with basalt masses solidifying during the formation of the volcanic cone.

2) The presence of oysters (Hill, 1890) in the volcanic material and corals found during the present work shows that the volcano was on the sea bottom.

3) A hand-dug well completed in January, 1952 on the southwest flank of Pilot Knob is situated on a basalt outcrop. The well penetrated about seven feet of basalt, followed by about 23 feet of more or less weathered "serpentinized" pyroclastics, three feet of basalt, and twelve feet of fresh "serpentinized" pyroclastics, the latter being in part very fine-grained sedimentary material containing many microfossils and much fossil debris. Nothing was seen at the outcrop to suggest that these flows are submarine. A portion of the volcano was probably above sea level, and it is likely that the flows at the point observed were on this portion.

4) The environment of deposition of the Austin chalk on the flanks of the volcano was different from that of the surrounding sea floor, and the features attributed at one time to contact metamorphism are here interpreted as being caused by an original difference in the sediments and a different diagenetic history influenced by the presence of the permeable pyroclastics.

5) The peripheral Austin chalk is well displayed only around the northwestern half of the volcano. It seems likely that originally Austin chalk may have been deposited to about the same level entirely around the volcano and that this level is not much above the outcrop of today. The later regional tilting southeastward would then have been sufficient to depress the Austin Chalk on the southeastern side of the volcano so that it does not crop out. The portion of the volcano above the level of the Austin chalk deposits was probably above sea level. In the cross-section (Fig. 2) the base of the "serpentinized" pyroclastics is depressed, suggesting that the area in the vicinity of the volcano subsided during the building of the cone.

6) Pyroclastic material is found to make up much more of the outcrop than originally thought. A thin-section study of the serpentine along Onion Creek near Upper McKinney Falls shows that it was originally pyroclastic rock and not a basalt. The inclusions of Austin chalk in the "serpentine" at this place are not xenoliths as originally thought but are blocks of Austin chalk which have become mixed with the "serpentine" during submarine slumping (mud flows of Durham, 1949).

The deformation caused by the slumping was well exposed during the spring

of 1950 on a dip slope on the west side of Pilot Knob in a trench dug by the Humble Pipe Line Company. The trench revealed that the Austin chalk is actually folded, faulted, and very thin, the deformation being of a type that could easily be formed by submarine slumping following the deposition of a thin layer of Austin chalk.

APPENDIX B

PHYSICAL MEASUREMENTS

Density Measurements

The interpretation of the gravity map naturally depends on the density differences existing between the geologic units in the area, and density data were accordingly obtained for the various stratigraphic units in the vicinity of Pilot Knob. All samples, except those of basalt, were collected in a saturated condition, and density determinations were made almost immediately. These densities should approximate the densities of the various rocks beneath the water table. The rocks above the water table will be somewhat less dense.

TABLE OF DENSITY DATA

Rock	Density, g/cm³		No. of Determinations
	Average	Range	
"Serpentine"	2.13	2.09–2.15	6
Basalt	3.16	3.13–3.20	8
Austin chalk, Little Walnut Creek	2.13	2.11–2.16	4
Austin chalk, Upper McKinney Falls	2.44	2.37–2.47	4
Taylor marl	2.18	2.14–2.25	7

The "serpentine" samples, representing two textural varieties, were collected near Upper McKinney Falls along Onion Creek for a distance of about 100 yards and through a vertical section of about 15 feet. Four samples of basalt were collected from the main mass and four from outlying masses. The average density for each group is 3.16. The Austin chalk from Little Walnut Creek is normal chalk well away from Pilot Knob and should be representative of the formation as a whole. The chalk from Upper McKinney Falls has a somewhat higher density caused perhaps by the high calcite content from fossils.

Density determinations have not been made for the Navarro group which underlies the eastern portion of the area. The only density contrast of importance in the area is between basalt, density 3.16, and the rest of the rocks, which have an average density of about 2.14, if the relatively unimportant portion of the Austin chalk, with density of 2.44, is disregarded.

Magnetic Susceptibility Measurements

Magnetic susceptibility determinations for "serpentine" and basalt made by the Bureau of Economic Geology and the Frost Geophysical Corporation are as follows:

TABLE OF MAGNETIC SUSCEPTIBILITIES

Description	Form	$K \cdot 10^{-6}$ (in cgs units)
1. Basalt	Flow	1,460
2. Basalt	Dike or flow	2,390
3. Basalt	Main mass	3,300
4. "Serpentine"	Fine-grained detrital	692
5. "Serpentine"	Coarse-grained detrital	4,160
6. "Serpentine"	In well beneath flow	67.5
*7. "Serpentine"	Fine-grained detrital	773
*8. "Serpentine"	Fine-grained detrital	778

* Determinations by J. C. Rollins, Frost Airborne Survey Corporation, on two portions of the same sample.

In general these results show a much smaller susceptibility for "serpentine" than for basalt, thus bearing out the observations discussed in detail above. However, one sample of "serpentine," number 5, gave a very high susceptibility. This sample contains much rather coarse magnetite, probably concentrated during sedimentation. These anomalous concentrations, of course, complicate the interpretation of the magnetic data.

In magnetic prospecting for so-called "serpentine plugs," it would be easy to miss those composed entirely of "serpentinized" pyroclastics. If unaltered basalt or "serpentinized" intrusives or extrusives are present, anomalies should be present even though under considerable cover, but their magnitude and steepness will be much reduced, since magnetic effects of di-polar bodies decrease with the cube of the distance. If Pilot Knob were buried under half a mile of sediments, an anomaly perhaps only one-twentieth as large as the original one would be observed.

Magnitudes of Magnetic Anomalies

The magnitudes of the magnetic anomalies observed over the oil fields discovered by the aerial magnetometer (Jenny, 1951) are as follows:

MAGNETIC ANOMALIES

	Aerial magnetometer 1,000′ above ground level, gammas	Magnetometer near ground level, gammas
New discoveries:		
Beyersville-Southwest	4	10
Coupland	5	15
Elroy-East	80	200
Elroy-Northeast		40
Lund	5	12½
Yoast-Southwest (dry)	20	25

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GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 455–458, 2 FIGS.

SPONTANEOUS POTENTIAL SURVEY OF A COPPER DEPOSIT AT SARIYER, TURKEY*

SULHI YÜNGÜL†

ABSTRACT

Several electrical methods were applied in the exploration for quartz-vein type chalcopyrite and auriferous pyrite deposits in the Sariyer area of Turkey. The spontaneous polarization method was found to be suitable for locating such deposits. The anomalies found by this method were tested by drilling and all of them showed sulphide masses. One of these, the Nalbant Çeşmesi anomaly, was partly developed afterwards and the geological section thus determined is in accord with the predictions based on the quantitative interpretation of the spontaneous polarization data. The sulphide mass here was found under a sterile cover of overthrusted schists. The topographic correction was of critical significance in locating this ore body.

The Byzantines are said to have mined copper in parts of the Sariyer area of Turkey during the fourteenth century. This area is located about 12 miles north of the center of Istanbul. Several geological surveys, as well as drilling and evaluation operations, have been carried on more recently (Alpay, 1950; Sagiroglu, 1952) without success. These operations were, unfortunately, conducted in the southern part of the mineralization area, down the slope, where the outcropping andesites, a few gossans, pyrite veinlets, and cupriferous waters attracted the explorers' attention.

Finally, in 1951, the whole area of probable mineralization was surveyed geophysically. Surprisingly, all of the sulphide bodies located by geophysical means happened to lie under a cover of unmineralized schists or alluvium and no important anomalies were found in the southern part which had appeared attractive to prospectors for so long a time.

The geophysical surveys made use of several electrical techniques and we may summarize them as follows:

1. A reconnaissance spontaneous polarization (S.P.) survey of the whole area (1.2 km square),
2. Detail S.P. surveys of two interesting sections (0.3 km square),
3. Resistivity profiles over two S.P. anomalies,
4. Line-electrode equipotential survey of one S.P. anomaly (0.01 km square),
5. "Outline determination—*mise à la masse*" survey of one sulphide mass (Nalbant Çeşmesi) after it was reached by an adit.

In this paper, only the Nalbant Çeşmesi detailed S.P. anomaly, its quantitative interpretation, and the geological section associated with it will be discussed. Although two other anomalies were tested by three bore holes, no core was obtained due to technical difficulties and lack of proper tools. These bore holes penetrated 15 m, 20 m, and 24 m into the sulphide bodies, and were abandoned

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while in the sulphide, because the sludge gave the impression that the sulphide consisted mainly of pyrite and the copper content was too low for exploitation. These two anomalies will probably be tested again in the future.

The mineralization is in the Senonian volcanic rocks. These eruptive rocks consist of andesites and tuffs. The sulphide masses occur where quartz is abundant and appear as quartz veins. They contain chalcopyrite, pyrite, gold, and secondary minerals, such as malachite, gypsum, and limonite (Alpay, 1950).

Application of the quantitative interpretation formulas previously published by the writer (Yüngül, 1950) to the Nalbant Çeşmesi S.P. anomaly (Fig. 1) leads to the following conclusions.

1. The concentric appearance of the S.P. anomaly and the lack of a positive center justify the assumption of a polarized spheroid whose axis of polarization is almost perpendicular to the surface ($\alpha = 0°$).
2. Considering the suitable profile (DD') passing through the center of the negative anomaly, the perpendicular projection of the spheroid center on the surface, O, coincides with the zero-potential-gradient point, namely the negative center, B. The maximum-potential-gradient point, C, on the SE side is about 10 meters away from B. The corresponding point on the NW side is not clear. The perpendicular distance, h, from the spheroid center to the surface, not considering the effect of topography on the distance CB, is

$$h = 2|CB| = 20 \text{ meters.}$$

3. The average dip of the surface, θ, is 22.5 degrees in the direction S 40° E. and the slope of the DD' profile, δ, is 21 degrees. The vertical depth to the center of the spheroid is

$$h'' = h/\cos\delta\cos\theta = 23.2 \text{ meters,}$$

and the location of the spheroid center on the map is at the point O'' whose distance from O is

$$OO'' = h\sin\theta/\cos\delta = 8.2 \text{ meters.}$$

The projection of the spheroid center on the geologic section is O_1 (Fig. 2).

The depth of the sulphide mass and the dimensions of the anomaly indicate that the sulphide is in the form of an elongated spheroid; its longest axis is almost parallel to the surface and its azimuth is 18°. This axis, shown with arrowheads on the map, was confirmed by the survey to determine the outline of the body.

Let us now compare the foregoing results with the geological section (Sagiroglu, 1952) indicated in Figure 2.

According to the sampling results, the sulphide mass can be divided into zones of 14% copper, 7% copper, 1–2% copper ores, and the pyrite zone. These zones are shown on the geological section as 14, 7, 1–2 and P respectively (Fig. 2). Up to date, the direct information concerning this sulphide mass consists practically of the given section.

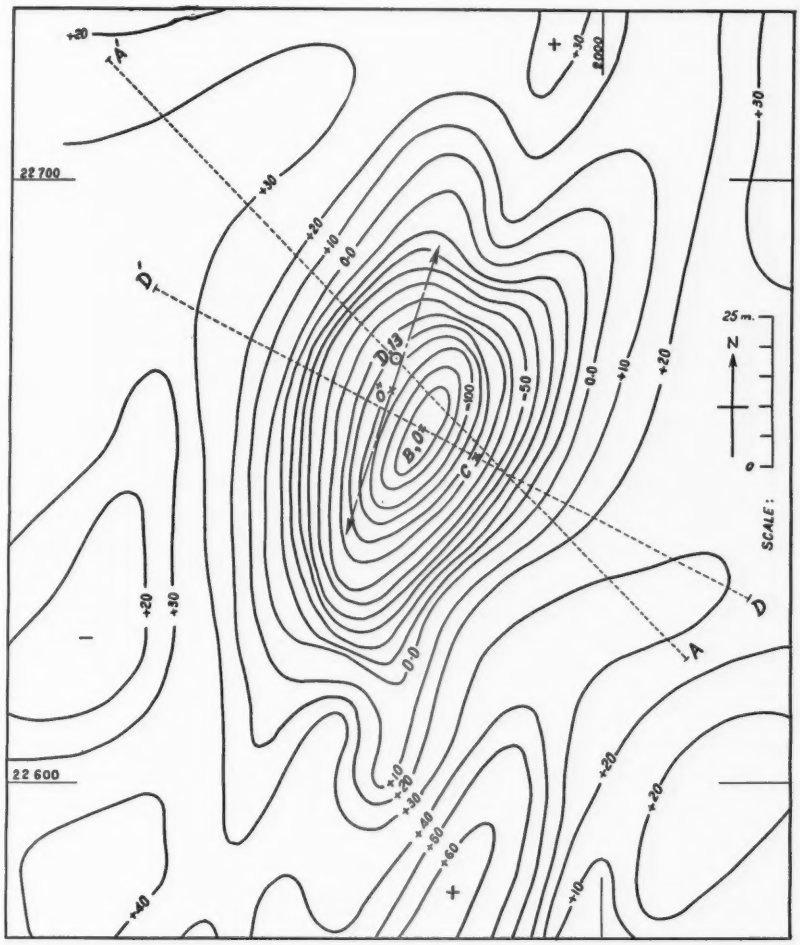

FIG. 1. Nalbant Çeşmesi. Spontaneous polarization anomaly, Sariyer, Istanbul, Turkey. Contour interval 10 millivolts.

The center of the sulphide mass as calculated from the S.P. results is approximately at the center of the actual ore body, excluding the low-grade part. The lower boundary of the sulphide mass, which is determined with sufficient accuracy, is almost parallel to the surface. Also, the section is of spheroidal form. All of these facts are in accordance with the geophysical results.

Because the mineralization in this area is in the form of quartz veins, the surface topography is quite rugged, and the water table is irregular, it might be said that the area covered by the geophysical survey appears unfavorable for spontaneous polarization work. The ore body discussed above was found under a cover of overthrusted schists. Even the mining geologist, Dr. G. Sagiroglu, in charge of the drilling, reasonably objected to our advice to drill at location D 13 for fear of wasting a drill hole over the sterile schists. Also, if the topographic cor-

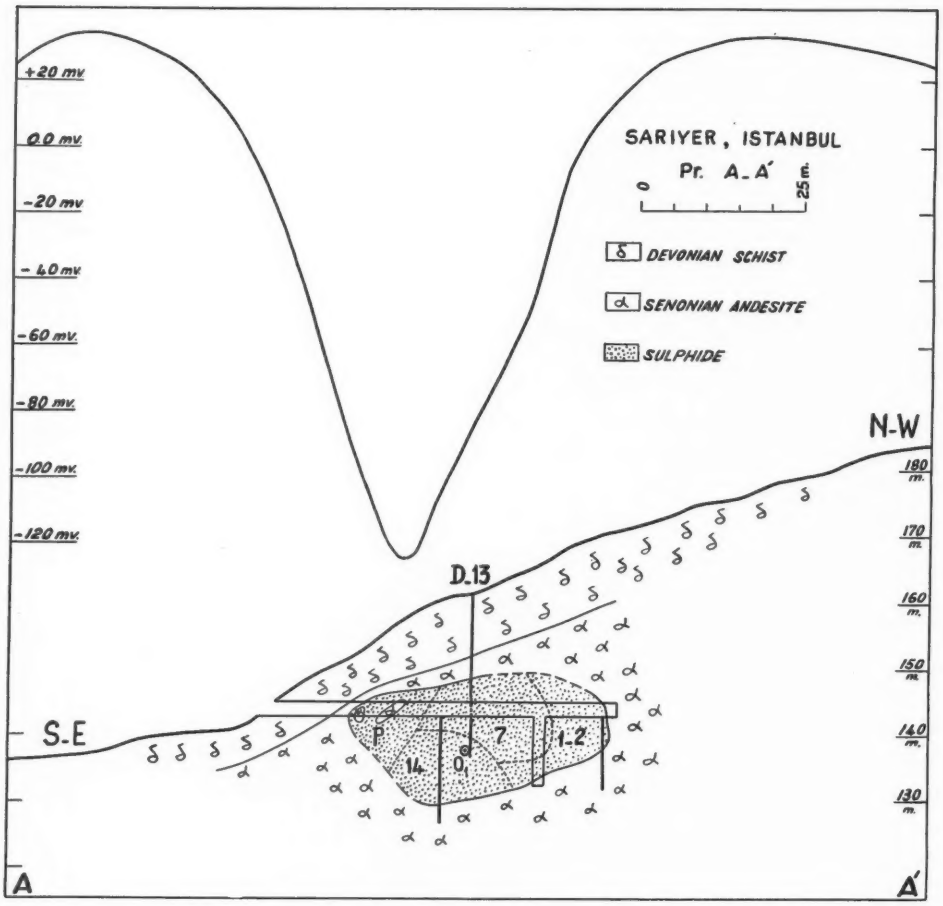

FIG. 2. Spontaneous polarization profile and geologic section, Sariyer, Istanbul, Turkey.

rections had been overlooked, a drill hole over the negative center would probably have shown nothing but pyrite. The results, however, turned out to be satisfactory.

ACKNOWLEDGMENTS

The writer wished to take this opportunity to thank the M.T.A. Enstitüsü, Ankara, Turkey, for rendering this survey possible and for permission to publish the results and conclusions.

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GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 459–477, 17 FIGS.

PROPAGATION OF RADIO FREQUENCY ENERGY THROUGH THE EARTH*

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ABSTRACT

Measurements have been made of some propagation characteristics in the earth of 1,614 and 1,700 kc radio frequency energy. The experiments were conducted at Carlsbad Caverns, New Mexico, and Mammoth Cave, Kentucky. Transmitters were set up on the surface 710 ft above an unwired tunnel in Carlsbad Caverns and the signal strength was measured at many points in the tunnels. A similar series of measurements was made in Mammoth Cave in a tunnel 270 ft below the surface. The data show that the attenuation constant is about 0.012 and 0.02 to 0.064 neper/meter at the two locations respectively. These values are in good agreement with theory.

INTRODUCTION

The speculation that radio frequency energy may penetrate the earth to depths much greater than allowed by theory and the possible applications of such a phenomenon have led to a number of experiments and much discussion in the geophysical literature (Pritchett, 1952; also see the bibliography at the end of this paper). A series of experiments conducted at Carlsbad Caverns, New Mexico and Mammoth Cave, Kentucky has furnished data which may aid in an understanding of the general problem.

The specific goal of this investigation was to determine the magnitude of the radio frequency energy penetrating into the earth under controlled conditions and to evaluate certain speculations regarding the propagation of this energy. The experiments turned out to be sufficiently successful that rather extensive conclusions could be drawn from the data obtained.

THEORETICAL CONSIDERATIONS

The field strength of a spherical radio wave passing through an attenuating medium may be expressed by the relation

$$E = (k/R^n)\epsilon^{-\alpha R} \text{ volts/meter} \qquad (1)$$

where k is a constant, R is the distance in meters from transmitter to receiver, α is the attenuation constant in nepers/meter (1 neper$\cong$8.7 db), and n is a constant of value one when $R \gg \lambda$, two when $R \ll \lambda$, λ being the wave length in the medium. This simplification of the rather involved equations defining the field is quite satisfactory for the present purpose. Equation (1) will be used later in the form $E \times R = k\epsilon^{-\alpha R}$. One notes at this time that a plot of $E \times R$ as a function of R on semilogarithmic paper should yield a line of slope $-\alpha$.

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The attenuation factor may be shown (Stratton, 1941, p. 276[1]) to be defined by:

$$\alpha = \omega \left\{ \frac{\mu\epsilon}{2} \left[\left(1 + \frac{\sigma^2}{\epsilon^2\omega^2} \right)^{1/2} - 1 \right] \right\}^{1/2} \tag{2}$$

where

α = attenuation factor (nepers/meter)
$\omega = 2\pi f$ (radians/sec)
f = frequency (cycles/sec)
μ = magnetic permeability of the medium (henry/meter)
$\epsilon = \kappa_e \epsilon_0$ = inductive capacity of the medium (farad/meter)
κ_e = specific inductive capacity
ϵ_0 = permittivity of free space (farad/meter)
σ = conductivity of the medium (mho/meter)

A plot of α as a function of σ is shown in Figure 17.

EQUIPMENT

Two battery powered transmitters were used. The characteristics are as follows:

	Transmitter Number 1	Transmitter Number 2
Power	14 watts	0.25 watt
Antenna	Two 125-foot insulated elements laid in line on the ground	One 80-foot insulated wire laid on the ground
Frequency	1,700 kc	1,614 kc

The receivers were battery-powered units, linear within the range used, with rotatable loop antennas. The approximate lower limit of linearity was reached for a reading of 16 units. Thirteen units of signal was equal to approximately one microvolt/meter. The signal levels received are given in Tables 1 and 2.

CARLSBAD CAVERNS

The first experimental site selected was Carlsbad Caverns, New Mexico (see Fig. 1). This cave offered a considerable length of unwired tunnel with good depth of cover and relatively easy access both on the surface and underground. In a preliminary investigation it was demonstrated that radio frequency energy penetrated to the cave level: a 1 kw, 740 kc station some 20 miles away in Carlsbad could be received.

The Left Hand Tunnel, Figure 2, was chosen as the underground work area; it was 3 to 50 feet wide, 5 to 100 feet high, dry except in the vicinity of stations 64 and 90*A*, *B*. The cover ranged from 750 feet at station 56 to 710 feet at station

[1] The α used in this paper corresponds to β in the notation employed by Stratton.

STATION NUMBER	NO. 1 TRANSMITTER AT A				NO. 2 TRANSMITTER AT A		NO. 1 TRANSMITTER AT C						
	TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA N 60°E		TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA NS		TRANSMITTING ANTENNA N45E		TRANSMITTING ANTENNA EW		
	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SI
Foot of Elevator					0				13	N35W			
Gate					0				*28	N88W	46	N2W	
56	32	N60W	40	N81W	0		133	N43W	58	N70W	142	N64W	
58	30	N69W	30	N60W	0				112	N22E	210	N61W	
59	40	E	38		0		436	N52W	140	N18W			
60	48	E			0						583	N43W	
61	38	N74E			0								
62	50	E			0		482	N16W	520	N5W	480	N62W	
63	132	N86W			A	N82W							
64	213	N82W	123	N83W	18	N83W	585	N4W	397	N10E	230	N82E	
64A													
65	300	N80W			25	E	324	N3W	403	N20E	261	N33E	
66													
66A	351												
67	648	N61W	165	N68W	39	N68W							
68							172	N2W	140	N23E	194	N26E	
69	1133	N53W	243	N65W	37	N65W							
70	1025	N48W			24	N88W	135	N25E	98	N28E	127	N37E	
71	1055	N69W	381	N70E	43	N80E							
72	1590	N75W			57	N75E							
73					70	N79E	62	N40E	24	N43E	61	N50E	
74	1130	N78W											
75					52	N72E	15	N42E	37	N42E	55	N42E	
76	1280	E											
78	1810	E			87	N82E	33	N57E	57	N58E	69	N58E	
80	2340												
83	3280	N84W			108	N68E							
88A	3560	N74W			112	N73E							
92													
90													
90A									*18 N20W				
90B									150 feet W of gate				

Table 1

Carlsbad Caverns Data

	NO. 2 TRANSMITTER AT C		NO. 1 TRANSMITTER AT D						NO. 1 TRANSMITTER AT H		NO. 2 TRANSMITTER AT			
	TRANSMITTING ANTENNA NS		TRANSMITTING ANTENNA NS		TRANSMITTING ANTENNA N45E		TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA EW		TRANSMIT ANTENNA	
	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BE
									50					
			37	N51E					53		A		0	
W	13	N45W	110	N45W	90	N46W	95	N46W	39	N78W	8	N88W	0	
W	20	N30W	95	N64W	110	N5W	68	N21W	24	N72W	7		0	
	58	N39W							71	N83E	30	N73E	0	
W			150	N26W	426	N26W	380	N37W	53	N85W				
											33	N83W	13	N
W	87	N11W	138	N56W	460	N20W	202	N23W	150	N88W	41	N79W	25	N
									220	N82W	47	N88W	29	
E	83	N3W	90	N78W	264	N4W	159	N7W	317	N89E	57	E	29	N
											70		43	
E	81	N6E	175	N27E	226	N4E	215	N7E	750	E	48		42	
													42	N
									742	E	49	E	33	N
E	38	N11E	208	N17E	225	N8E	259	N4E			40	N88W	34	N
									1020	N88E	38	N68E	35	N
E	17	N10E	118	N39E	52	N18E	82	N25E	762	N86E	35	N63E	23	N
									742	N80E	33	N65E	19	N
									610	N86E	25	N68E	8	N
E	10	N39E	59	N50E	23	N35E	49	N50E	428	N79E	12	N72E	5	
	9	N42E									12	N72E	0	
E	7	N18E							329	N65E	7			
									426	N76E	15	N88W		
									470	N78W	A			
									321	N56W	A	N58W		

NO. 2 TRANSMITTER AT J				NO. 1 TRANSMITTER AT K								NO. 2 TRANSMITTER AT W		
SMITTING NNA EW		TRANSMITTING ANTENNA NS		TRANSMITTING ANTENNA NS		TRANSMITTING ANTENNA N45E		TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA EW		TRANSMITTING ANTENNA EW		STATION NUMBER
BEARING		SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	SIGNAL	BEARING	
														Foot of Elevator
		0		A		11	N87E	7	E					Gate
N88W		0		0		6	N80W	7	E	A				56
		0		A		A		7	E	A		2270	N57E	58
N73E		0		A		7	E	10		A				59
								10				405	N80W	60
N83W		13	N7W	0		A								61
N79W		25	N9E	0		A		12	N80W	5	E	97	N67E	62
N88W		29	N	0		A		14	N82E					63
E		29	N8E	0		9	N72W			6		64	N46E	64
		43	N			8	N85W							64A
		42	N			7	N67W			7	N80W	10	N83W	65
		42	N11E			8	N57W							66
														66A
E		33	N26E	3		12	N25W							67
N88W		34	N16E	A		8	N60W	10	N72W	6	N65W	A	N70E	68
N68E		35	N24E	5	E	7	N58W							69
N63E		23	N39E	0		13	N77W	15	E	8	E	0		70
N65E		19	N42E	6	N17W	9	N35W							71
N68E		8	N13E	10	E	39	E							72
N72E		5		23	N50W	44	N86E	40	E	21	N87W	0		73
N72E		0		24	N56W	42	N86E	32	E	29	E			74
				39	N45W	23	N39E	18	N10W	7	N18E			75
								16	N45W					76
N88W				53	N24W	58	N45E	30	N56W	A	N42W			78
														80
				45	N6E	33	N22E	43	N8W					83
N58W				190	N30E	170	N33E	140	N40E					88A
				145		173	N40E	150	N48E					92
				118	N26E	145	N32E	125						90
				240	N40E	140	N60E	112	N73E					90A
				648	N40E			631	N42E					90B

Table 2

Mammoth Cave Data

NO. 2 TRANSMITTER AT D			NO. 1 TRANSMITTER AT E		
STATION NUMBER	TRANSMITTING ANTENNA N60W		STATION NUMBER	TRANSMITTING ANTENNA N45W	
	SIGNAL[4]	BEARING		SIGNAL[5]	BEARING
OB - Olive's Bower	1300	N37W	1[1]	A	N65W
100	130	E	2[1]	A	N50W
MP Mushroom Pits	210	N70W	3[1]	8	N55W
101	190	N87W	4[1]	17	N45W
102	125	N83E	5[1]	33	N35W
103	83	E	6 (William's Dome)	32	N38W
104	23	N45W	7	53	N60W
105	0		8	60	N45W
106	0		9	42	N35W
107			10 (Thorpe's Pit)	25	N25W
108	A	N65W	11	22	N35W
109	0		12	3	N55W
110			13	0	
111	0		14	A	N80W
113	14[2]	N50W[3]	15 (Bow of Great Eastern)	0	
114	22[2]	N60W[3]	16	A	N60W
115 Mammoth Dome	87[2]	N65W[3]	17	A	N
116	67	N70E[3]	18	O	
117 Saltpeter Vats	0		19	A	N85W
118 Gate	36[2]	N60E	20	A	N80E

[1]Cable on floor of tunnel at these locations.

[2]True reading 10 to 50 percent greater than this, due to equipment failure.

[3]Magnitude and direction of signal affected by signal on electric wiring.

[4]Six units equals approximately 1 microvolt.

[5]Thirteen units equals approximately 1 microvolt.

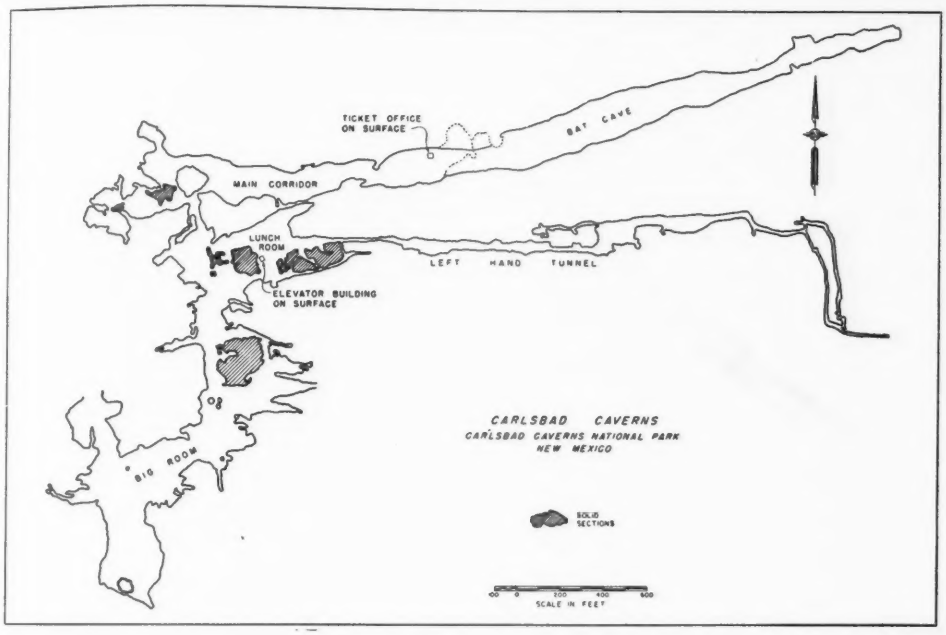

FIG. 1. Map of Carlsbad Caverns.

74. In Figure 2 transmitter locations are shown by symbols such as $A(1, 2)$, meaning station A at which transmitters 1 and 2 were used. Also in Figure 2 there is shown a table of transmitter positions with the antenna orientations employed at each point. All positions except W were on the surface; W was located at the end of the wiring and piping in the Left Hand Tunnel. The underground receiver station numbers are survey points from a National Geographic Society survey of the Caverns.

In practice the transmitters were set up at one or two points on the surface and traverses of the tunnel were made, readings being taken at various points. The receiving antenna was rotated for maximum signal reception and the orientation recorded as well as the numerical signal value. These data are given in Table 1. In this summary all values for a given run are reduced to a common base, but one should not attempt to move across the table; i.e., a signal of value 100 for a given transmitter and receiver location does not necessarily mean the same thing as a value of 100 for a different transmitter position. The introduction of power to the earth can be substantially affected by any change in the conditions at the transmitter.

Figures 3 through 11 present the data in a more easily assimilable form. It is somewhat easier to visualize these data when they are presented in the form used in Figures 3 through 6. The received signals are represented by arrows whose lengths are proportional to the signal strength and whose directions indicate the

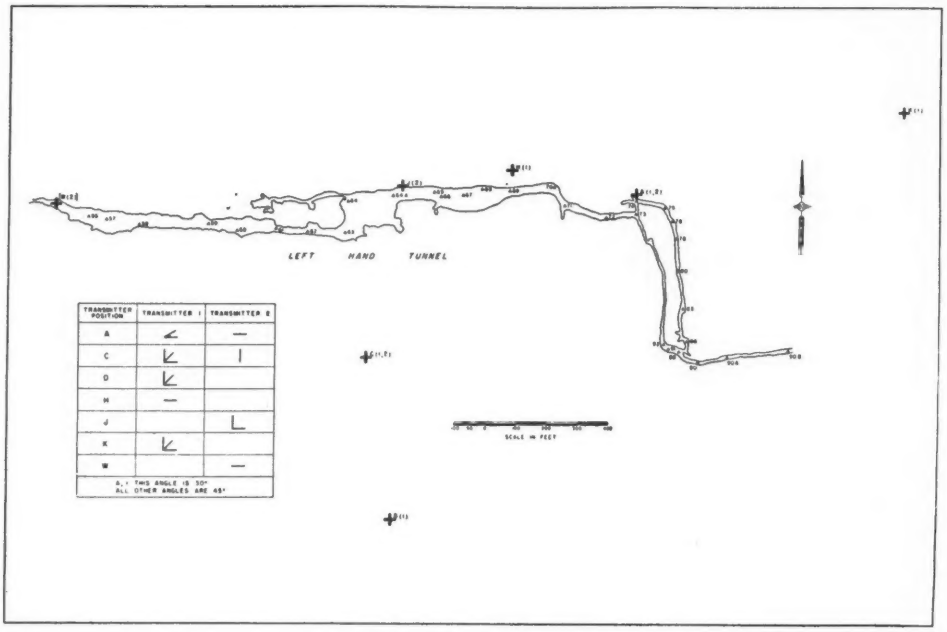

FIG. 2. Map of Left Hand Tunnel, Carlsbad Caverns, showing surface and subterranean transmitter locations.

receiving antenna orientations. The 180-degree ambiguity inherent in a loop antenna has been resolved on the basis of practical considerations. The double-ended arrows under the transmitters represent signals for which this resolution could not be made. Circles are used at some points where directions were not recorded. At many points the signal was audible over headphones but was not strong enough to deflect the meter. Dashed lines show the loop antenna orientation in these cases.

The outstanding feature of these drawings is the maximum in the strength of signals where the distance from the transmitter is a minimum. This was taken as conclusive evidence that the radio frequency energy was coming down directly through the earth.

To answer the expected criticism that energy might have been coming in through the Natural Entrance or by way of the elevator, surveys were made which demonstrated conclusively that there was not enough energy entering by these paths to be detectable in the Left Hand Tunnel with the receivers used. To further settle this point, the number 2 transmitter was set up at *W*, where the wiring and piping ends in the Left Hand Tunnel, and a survey was made down the tunnel. The results, as given in Figure 11, are conclusive. The signal at station 58 was almost the maximum that could be read; the signal at station 65 was below the linear range of the receiver and cannot be shown as a solid arrow on the scale

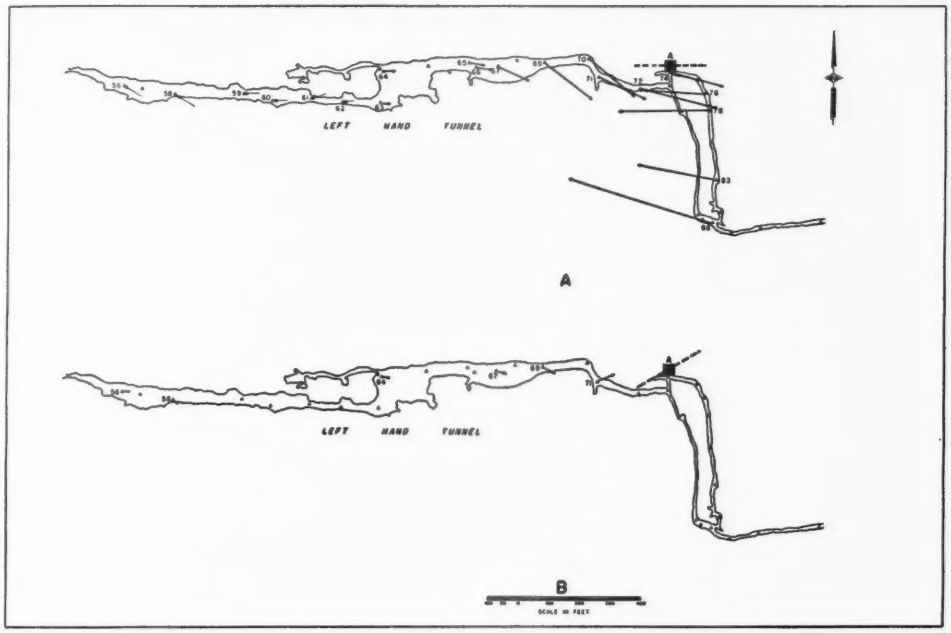

FIG. 3. Vector plot of data for Number 1 Transmitter at A, Carlsbad Caverns.

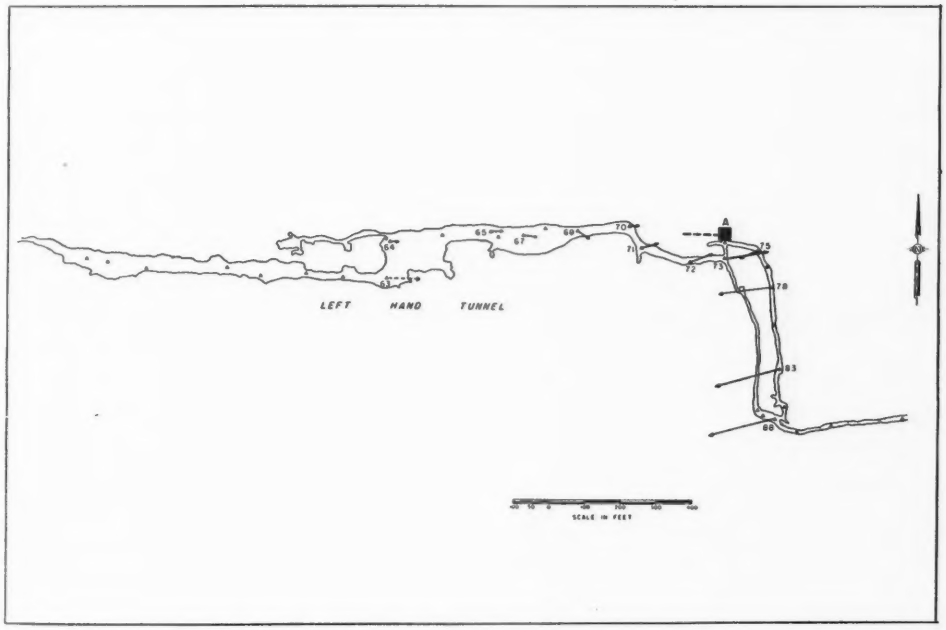

FIG. 4. Vector plot of data for Number 2 Transmitter at A, Carlsbad Caverns.

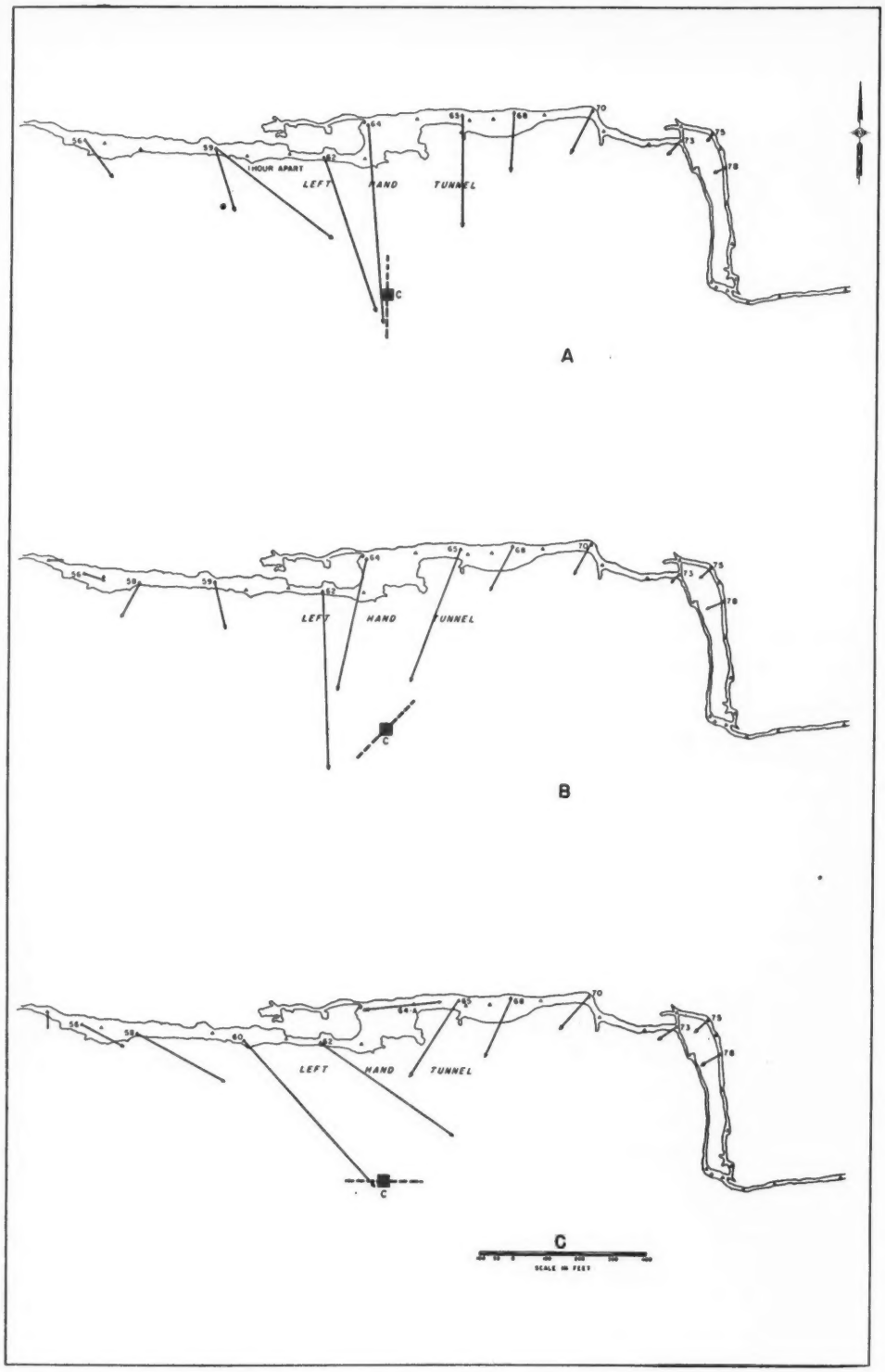

FIG. 5. Vector plot of data for Number 1 Transmitter at C, Carlsbad Caverns.

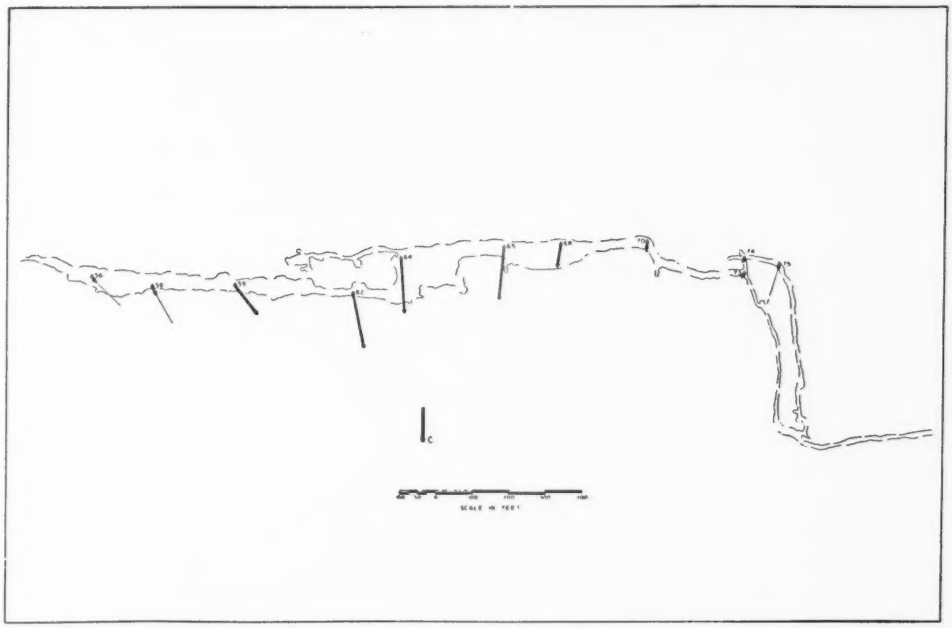

FIG. 6. Vector plot of data for Number 2 Transmitter at C, Carlsbad Caverns.

employed. It follows then that no signal could have come in from the cavern entrances to interfere with the direct signal.

An analysis of the data led to the rather unexpected conclusion that the radiation pattern underground of the antenna arrays is hemispheric, i.e., that the system radiates equally well over all the angles observed. This conclusion permitted application of the simplified equation for field strength, $E=(k/R)e^{-\alpha R}$, to the data.

All of the data which did not show obviously irrational deviations were plotted in the form $E\times R$ as a function of R. The resultant curves for the various runs were normalized to a common base at $R=1{,}000$ feet. These data are presented in Figure 12.

Signals read on the non-linear portion of the receiver scale are plotted as triangles in Figure 12. Audible signals which were below the range of visual readability are shown by arrows along the R axis, as are the pertinent zero signals; i.e., the first point in a traverse where the signal was no longer either audible or readable.

A satisfactory representation of the first portion of these data is given by the line $\alpha=0.012$ nepers/meter, or about 0.032 db/ft. The exact value is not of great importance; it can be varied by 20 percent by normalizing at other points, or by other means.

There are a number of points from 1,100 to 3,000 feet which indicate that an

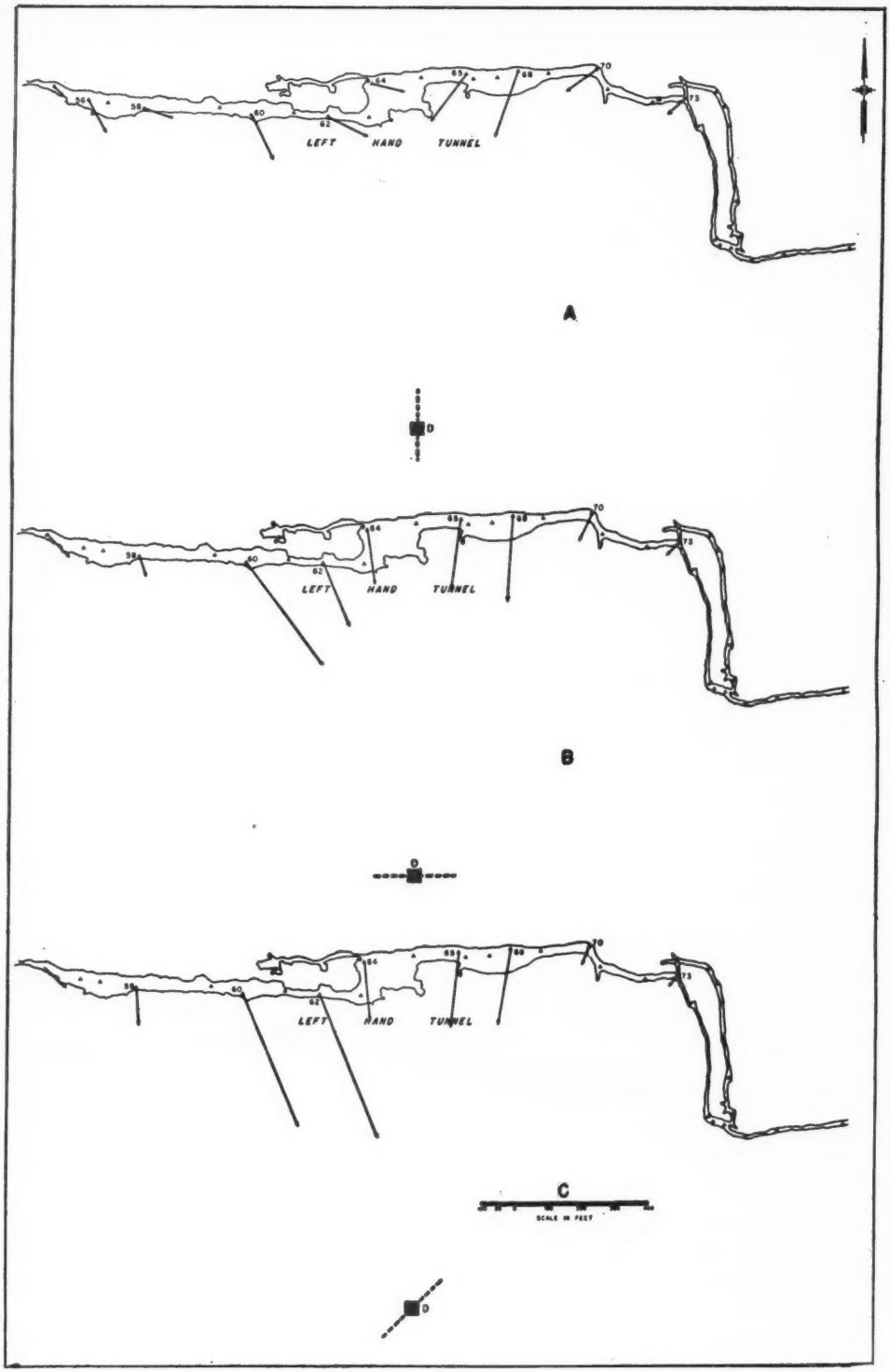

FIG. 7. Vector plot of data for Number 1 Transmitter at D, Carlsbad Caverns.

essentially zero attenuation line might be drawn. There is considerable evidence that these signals were affected by contributions from the energy in the air above the cave. It is known that a radio wave traveling over the surface of the earth loses energy into the earth (Terman, 1943, p. 697). In the neighborhood of the transmitter the air wave is changing in strength with distance relatively slowly compared with the rate of change of the underground signal. Hence if a given percentage of the air signal is lost into the earth as one moves away from the transmitter, and if a given percentage of this reaches the cave level, then at some point P this signal will be greater than that which arrives at P directly from the transmitter. For greater distances the rate of decline of the observed signal will be fixed by the rate of decline of the air signal. This appears to be explanation for the "zero attenuation" region in Figure 12.

Further evidence supporting this hypothesis is afforded by an examination of the polarization information furnished by the antenna orientations. The best example of this is Figure 9. One notes that when the transmitting antenna was rotated 90 degrees on the surface, the receiving antenna in the cave below had to be rotated 90 degrees for maximum signal reception, that is, the receiving antenna appears to tend to parallel the transmitting antenna (where normally one expects the loop to point to the source). This effect has been noted to distances as great as $R=1{,}200$ feet, and at greater distances it is definitely not present. To date, the only tenable hypothesis offered in explanation of this phenomenon is that the radiation underground which comes directly from the transmitter is polarized in the sense of the antenna. In the air the radiation is known to be vertically polarized; energy refracted into the earth from the air signal would then have its electric vector in the plane determined by the source and the air vector.

It might be pointed out at this time that, assuming the correctness of this explanation, had the work at Carlsbad Caverns been limited to distances greater than 1,100 feet an entirely false value of the attenuation factor would have been gained.

It may be shown (Stratton, 1941, p. 276) that the wave length of 1,700 kc radiation in the earth at Carlsbad Caverns should be about 180 feet. The preceding analysis of the data might be criticized on the basis that the distance R was not great enough. In anticipation of this objection, the data were re-evaluated on the basis of the equation $E\times R^2=ke^{-\alpha R}$. The value of α obtained is not significantly different from the value found from $E\times R=ke^{-\alpha R}$; the high value of α controls the function.

There is a great deal of scatter in the points in Figure 12. Figure 13 is attached by way of explanation. One sees that a very small deviation in a linear plot of the data becomes greatly distorted in the semilog plot of the $E\times R$ function. Such small deviations are to be expected in taking data of this sort. The position of the receiving loop with respect to the cave walls, slight differences in tuning, etc., were enough to cause minor variations in the signal. (To minimize

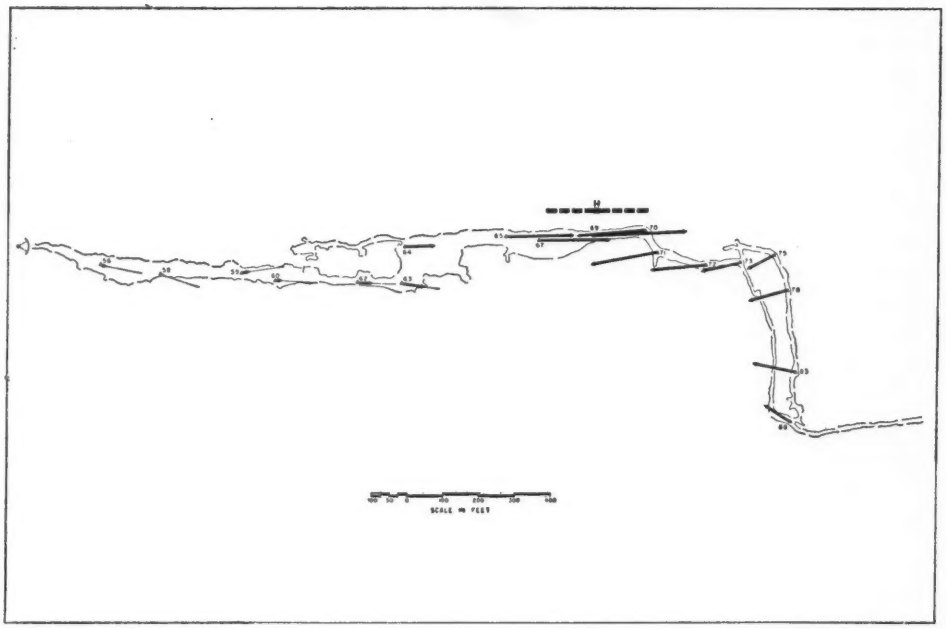

FIG. 8. Vector plot of data for Number 1 Transmitter at H, Carlsbad Caverns.

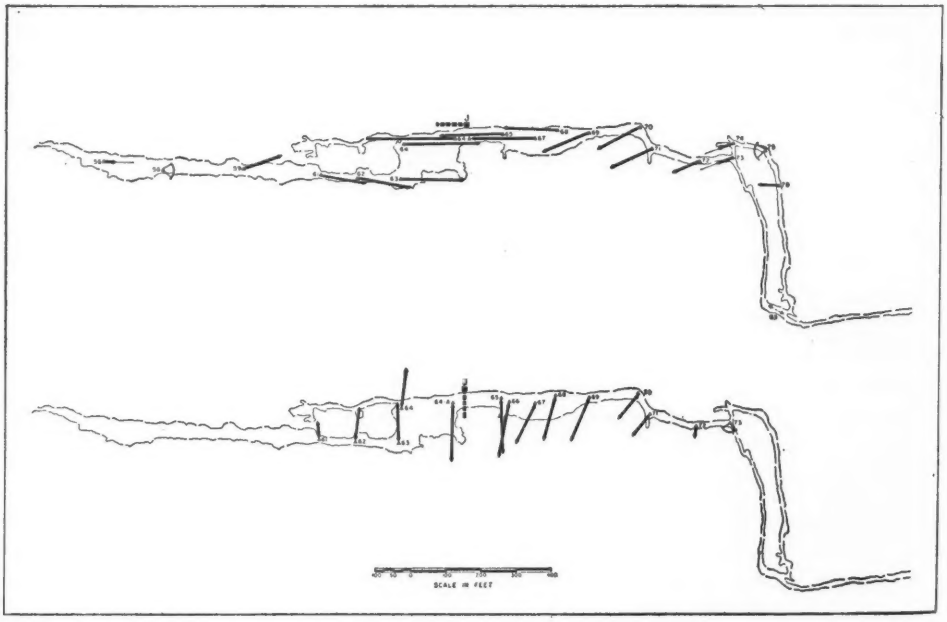

FIG. 9. Vector plot of data for Number 2 Transmitter at J, Carlsbad Caverns.

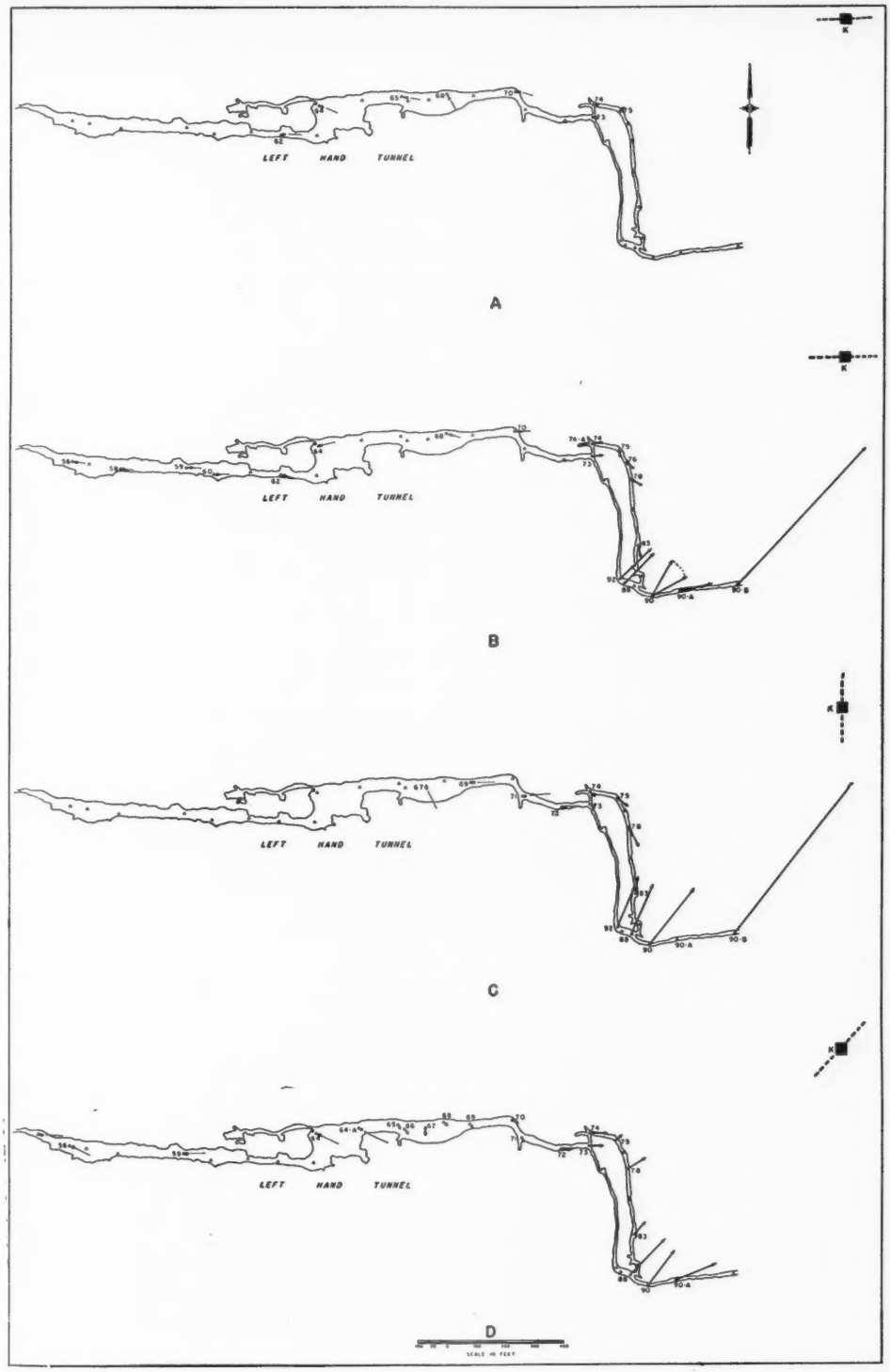

FIG. 10. Vector plot of data for Number 1 Transmitter at K, Carlsbad Caverns.

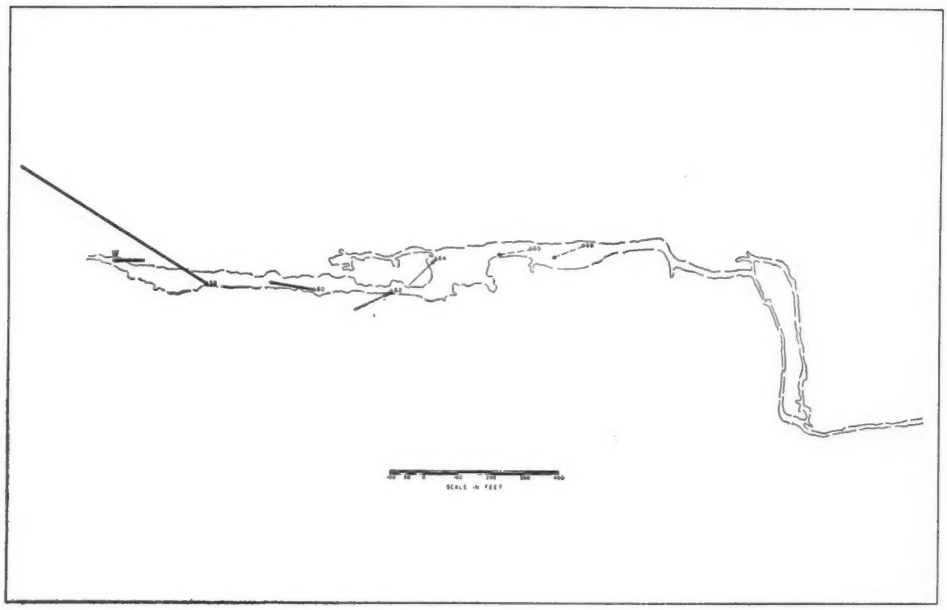

FIG. 11. Vector plot of data for Number 2 Transmitter at W, Carlsbad Caverns.

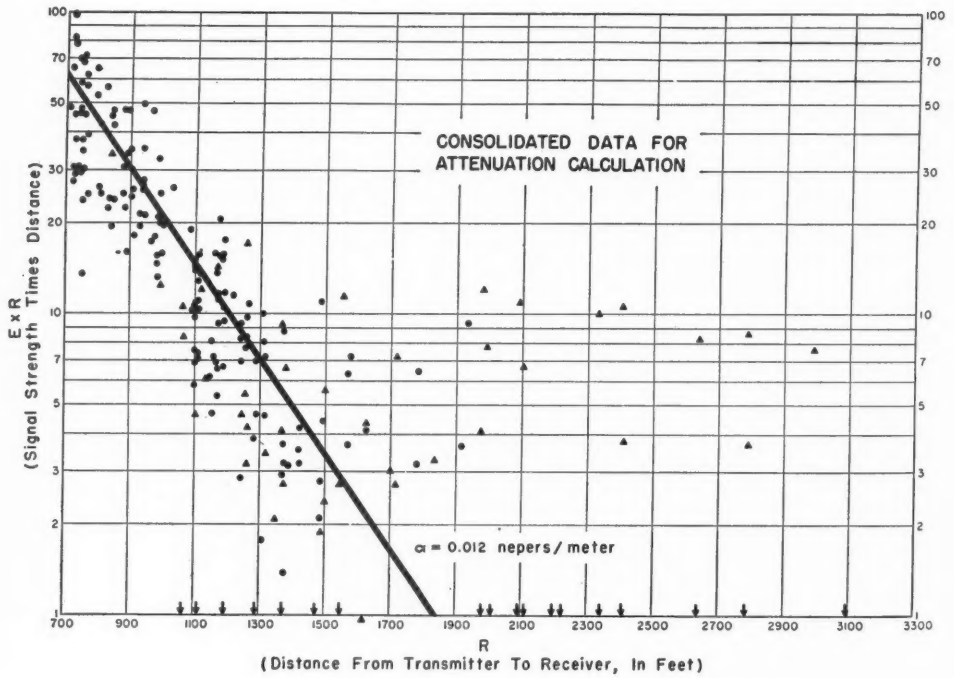

FIG. 12. Signal strength times distance as a function of distance, Carlsbad Caverns.

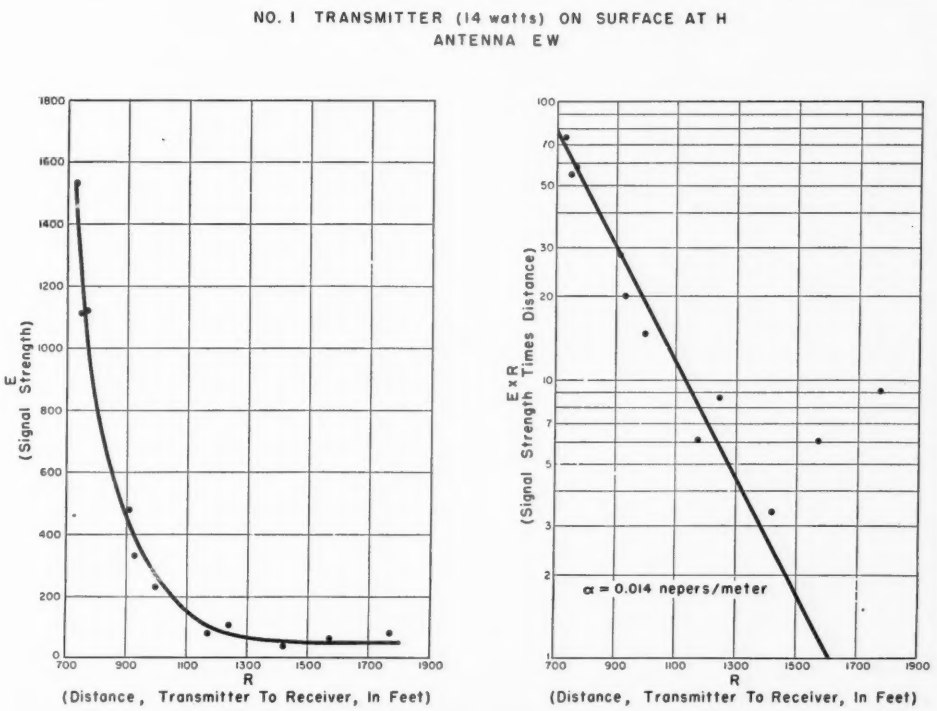

FIG. 13. Effect of small signal variations on scatter of data, Carlsbad Caverns.

the effect of the first of these difficulties, the receiver was set up at the same point each time.) As has been specified previously, one cannot place great reliance on any point. The data must be treated as a whole if one is to draw a broad conclusion from them.

The number 2 transmitter set up at various points in the Left Hand Tunnel was at times used to obtain communication with surface stations as far removed as *D*.

MAMMOTH CAVE EXPERIMENT

The results of the work done at Mammoth Cave, Kentucky, are not so clear-cut as the Carlsbad Caverns results.

The maximum cover at Mammoth Cave is a little greater than 300 feet; the cave is very extensive, almost four miles air line between the most widely separated entrances, or seven miles by cave passages; it offers a number of areas suitable for experiments of this sort, there being many passages at a suitable depth which are remote from wiring and piping. The overburden conductivity was known to be greater than at Carlsbad Caverns.

Three general experimental sites were occupied at Mammoth Cave, as indicated on Figure 14, a map of the area. The experimental procedure and apparatus were the same as those employed at Carlsbad Caverns.

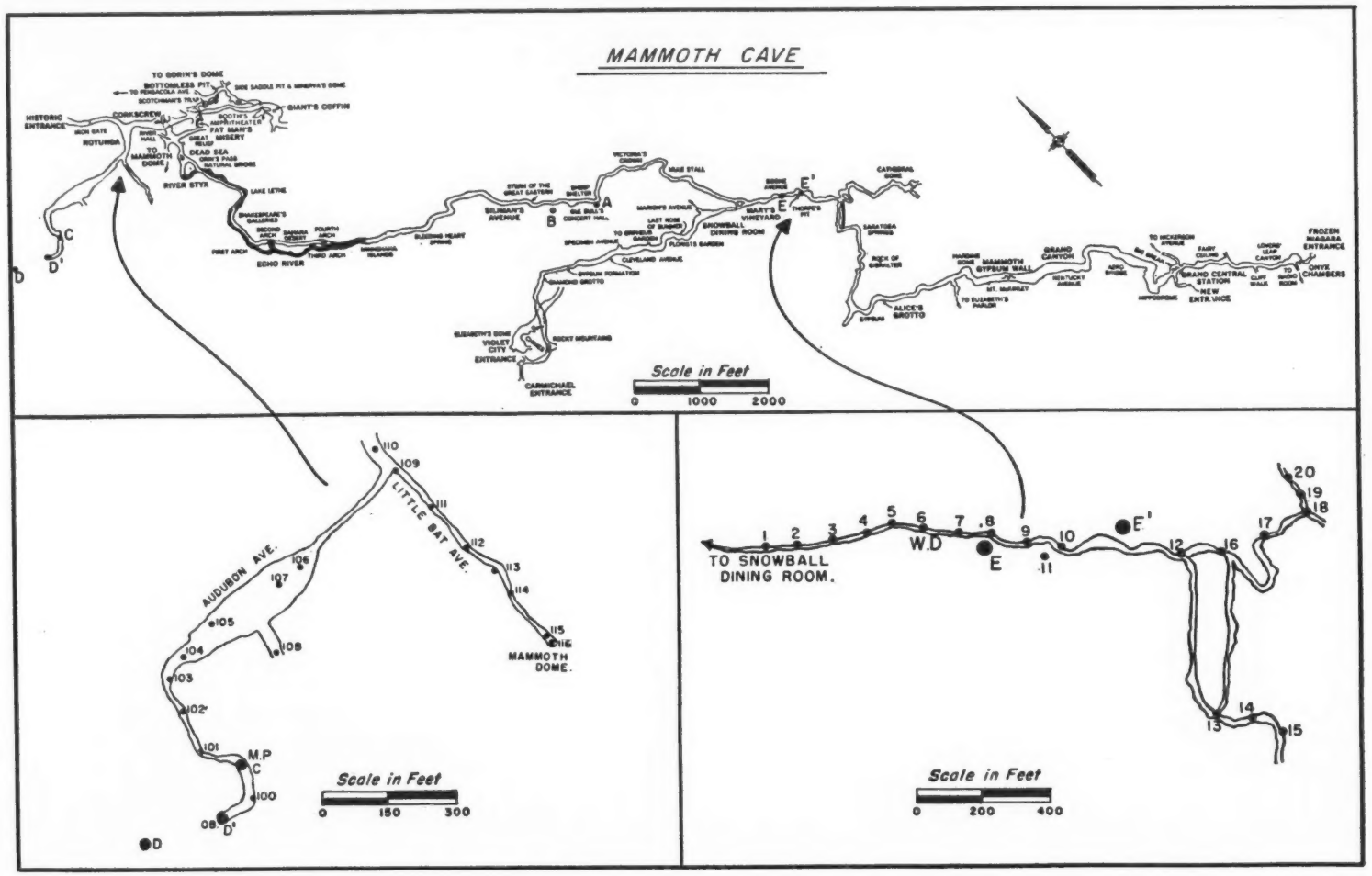

FIG. 14. Map of Mammoth Cave.

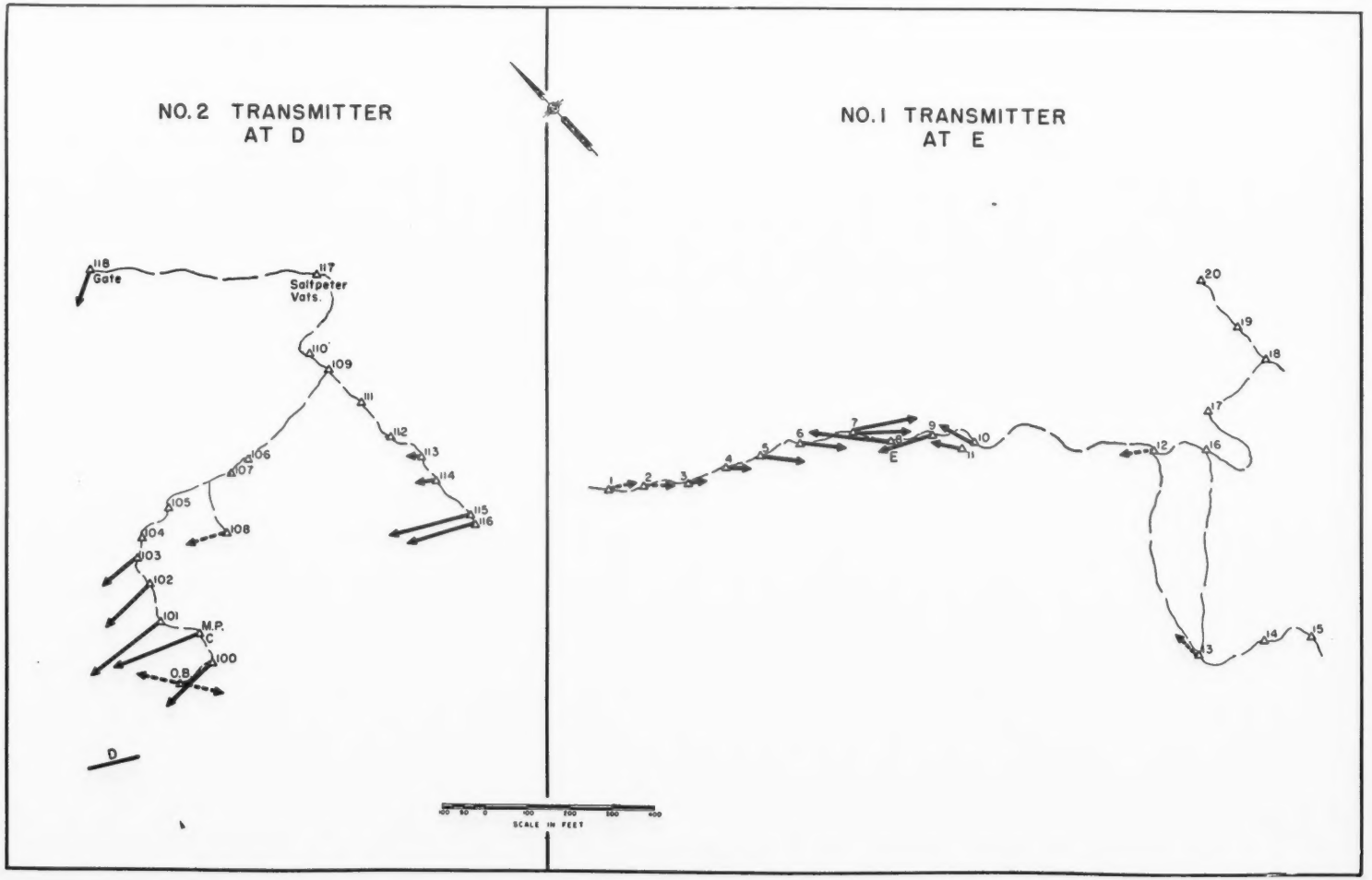

FIG. 15. Vector plot of data at Mammoth Cave.

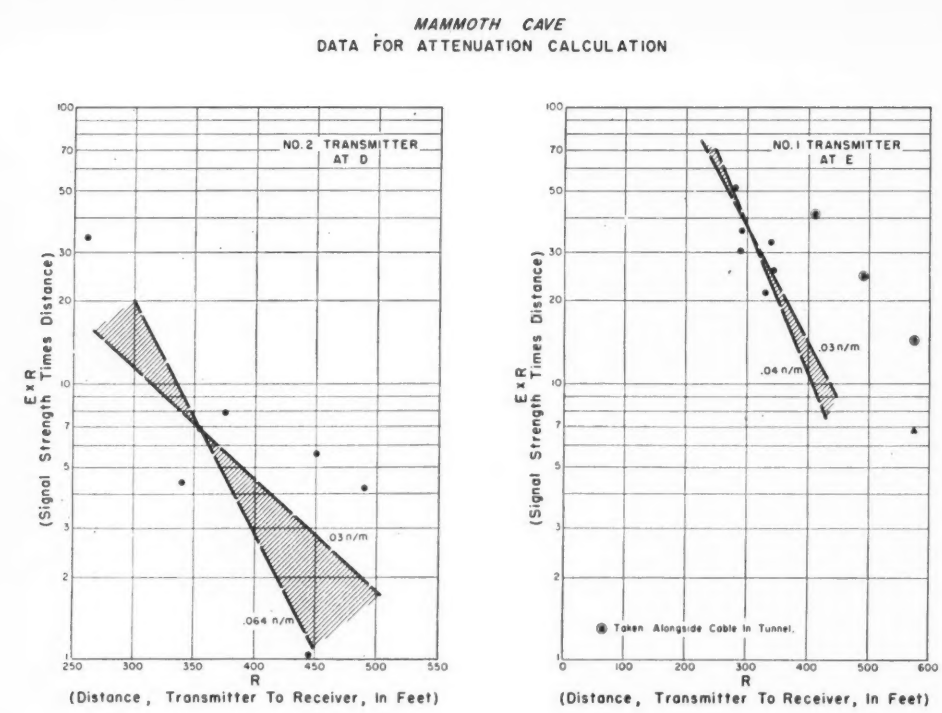

FIG. 16. Signal strength times distance as a function of distance, Mammoth Cave.

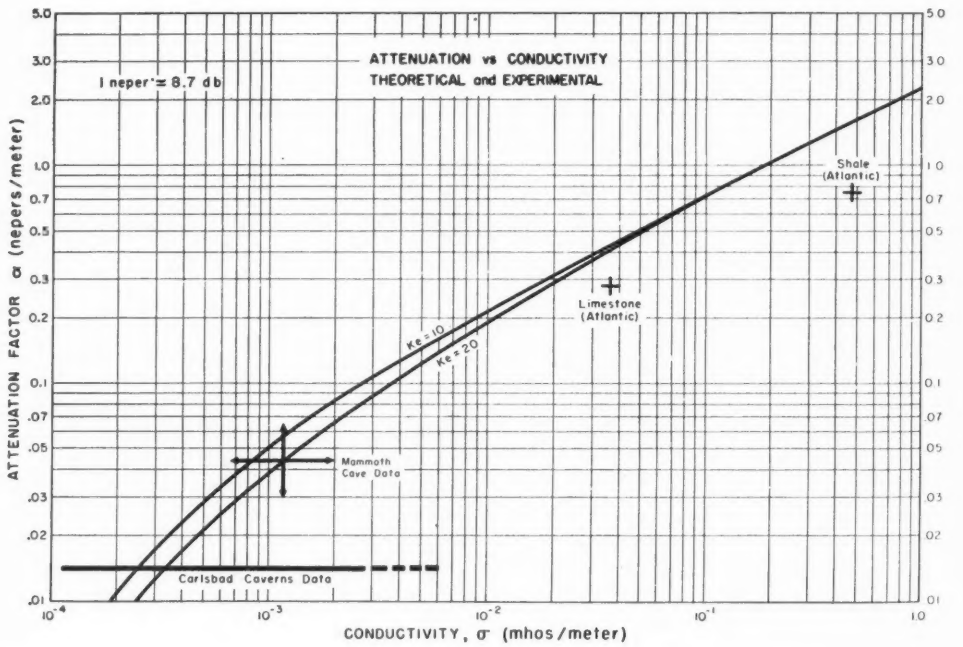

FIG. 17. Attenuation constant as a function of conductivity.

Both transmitters were set up on the surface at *A* and *B*, and a traverse made under them at about 270 feet of depth. No signal was received. In the tunnel from Carmichael Entrance to the Dining Room signals were received, but these were traced to the electrical wiring of the cave in this region. This wiring terminates just beyond the Dining Room.

New sites were occupied in an effort to get further data. The number 1 transmitter was set up at point *C* and the number 2 transmitter at point *D*. Traverses were then made as indicated in Figures 14 and 15. The data were complicated by the presence of electrical wiring except in Audubon Avenue from 107 to Olive's Bower (O.B. on the map). Station locations here were located by stepping off distances along a compass bearing from known points. In the vicinity of the antennas the geometry was poor. The cover was 50 feet at *C* and 30 feet at *OB*, less in both places than the antenna lengths. Data taken with transmitter number 1 was either off scale or unusable for a reason that will be discussed in the next paragraph. For this reason only data from transmitter number 2 is reported in Figure 15 and Table 2.

At points 103, 107, and 108 a peculiar effect was noted when working with transmitter number 1. The receiver showed a maximum signal for only one orientation of the receiving antenna, going to a minimum when the antenna was rotated about 90 degrees. The effect was not observed only at an isolated spot, as the receiver was moved about freely over a low hill in the cave. It was not due to any discoverable wiring effect, as it persisted for all conceivable positionings of the antenna and receiver.

One notes an increase in signal strength in Little Bat Avenue as one moves away from the transmitter. Power is brought into the cave through the top of Mammoth Dome. The logical conclusion is that energy has been introduced into the earth and has emerged in Mammoth Dome on the wiring with sufficient strength to make a major contribution to the signal at this point.

As a final phase of this work the number 1 transmitter was set up at *E* and very carefully tuned. Every measure possible was taken to couple maximum energy to the earth. A traverse was then made in the cave, yielding the results in Table 2 and Figure 15. There is approximately 270 feet of cover in this area.

The data from the two runs with transmitters at *D* and *E* are far from satisfactory from the standpoint of both quantity and scatter, as is evident in Figure 16. One might set the limits indicated there, 0.03 to 0.064 neper/meter, for the attenuation factor α.

CONCLUSIONS

Figure 17 is a plot of attenuation versus conductivity of the transmission medium. The two lines are theoretical values (see THEORETICAL CONSIDERATIONS) for different values of the specific inductive capacity. The conductivities represented include the general range for limestone. The attenuation value indicated for Carlsbad Caverns is shown as a line since the conductivity was not measured. There had been no rain of note for some two years. The value

checks theory well within an order of magnitude. Extreme limits are set for the attenuation and conductivity measured at Mammoth Cave. Two points reported by Pritchett (1952) are shown, for a shale and limestone medium. The limestone point is based on very scanty data.

The impression gained from Figure 17 is that the experimental data available checks theory satisfactorily; hence the theory is apparently applicable to the propagation of radio frequency energy through the earth.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the wholehearted cooperation of Mr. R. T. Hoskins, Superintendent of Carlsbad Caverns National Park, of Mr. Thomas Miller, Superintendent of Mammoth Cave National Park, and of their staffs. Mr. William Barret of Shreveport, Louisiana very kindly furnished much of the equipment used. Permission of United Gas Corporation to publish the foregoing results of experimental work is gratefully acknowledged.

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DISCUSSION BY W. C. PRITCHETT*

This paper presents a large amount of data which rather conclusively answers the question: "Are radio frequencies practical for use as signals in prospecting for oil?" By presenting the basic data so completely, the author makes it possible for those sufficiently interested in this work to draw their own conclusions in regard to (1) the earth radiation pattern, (2) the reason for slow signal decline for $R > 1{,}200$ feet, and (3) various other aspects of the work.

From an academic viewpoint the work would have had more general value if some measurements of earth resistivity had been made.

* The Atlantic Refining Co., Dallas, Tex.

GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 478–489, 6 FIGS.

A FIELD EVALUATION OF THE ELECTROMAGNETIC REFLECTION METHOD*

ALBERT ORSINGER†‡ AND ROBERT VAN NOSTRAND†

ABSTRACT

Previous publications have outlined the general theory of electromagnetic wave propagation along an interface such as the air-earth boundary and described model experiments in which this theory was verified. Equipment similar to that described for the laboratory experiments has been adapted for field use. Two large loops, one for transmitting and the second for receiving, are laid on the surface of the ground and a current square wave is passed through the transmitting loop. A similar arrangement of loops is placed on the surface of a metallic model. The signals from the two receiving loops are mixed in opposition. The layering in the model is then manipulated until the difference signal is a minimum, which condition signifies that the actual earth has been approximated in the model, after account is taken of the appropriate scaling factors. At five stations in Dallas County, Texas, this technique was used to determine the depth of the Austin chalk-Eagle Ford shale contact, which varies from 50 to 400 feet, within an average accuracy of about five per cent.

INTRODUCTION

A previous publication (Yost, 1952) outlined the general theory of electromagnetic wave propagation along an interface such as the earth-air boundary. A second paper (Yost et al., 1952) described a series of metallic model experiments which verified the theoretical treatment and presented experimental solutions to layered-earth problems too complicated to treat theoretically. The present paper, in which we present a field investigation of electromagnetic reflections in the earth, is a sequel to the earlier publications.

The field technique consists of laying two loops of wire 245 feet square on the ground separated 745 feet between centers, one to constitute a transmitter and the other a receiver. Most of the energy which travels from the transmitter to the receiver is transferred by a boundary wave travelling along the earth's surface. It is necessary to remove this boundary wave from the received signal if the reflected signal is to be interpreted in terms of subsurface geology (Fig. 1). This cancellation is effected by generating a similar boundary wave on the surface of a homogeneous metallic model and using this wave to cancel the boundary wave received by the loop on the ground. In the field the cancellation process is carried to the point of constructing, by trial and error, a metallic analogue of the layered earth so that the whole transmitted signal is cancelled and not just the boundary wave. The criterion for deciding when a proper analogue has been constructed is the degree of cancellation of the signal from the earth by the signal from the model.

The southern part of Dallas County, Texas (Fig. 2) is well adapted for an

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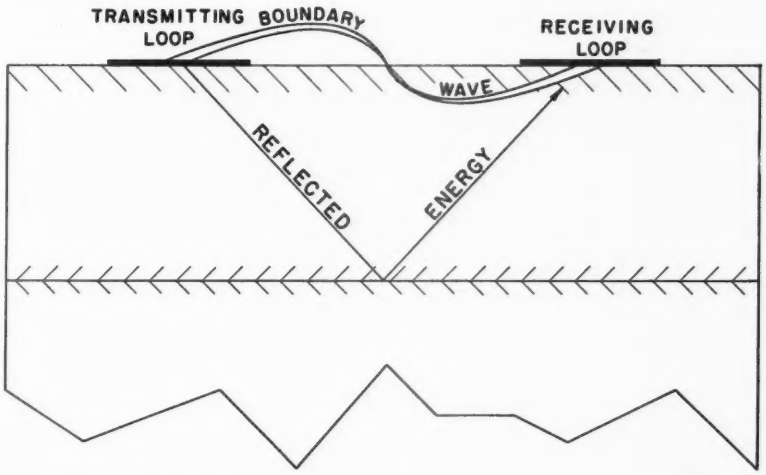

FIG. 1. Schematic diagram illustrating high fraction of total energy transmitted in the boundary wave.

initial field test of the electromagnetic reflection method. A shallow, easily recognized lithologic boundary is marked by a strong resistivity contrast. The surface formation, which in most places is covered by only a thin veneer of soil, is the Austin chalk whose resistivity varies from 20 to 40 ohm-meters. The underlying formation is the Eagle Ford shale which is about 500 feet thick and whose resistivity is less than 5 ohm-meters. Both formations are Upper Cretaceous in age. The contact between the two formations dips eastward at a rate of about 30 feet per mile. Although the weathered layer at the surface sometimes had to be considered, the thickness of the Eagle Ford is such that it could be regarded as infinite for the purposes of this experiment. The purpose of this work was to determine the depth to the interface between the Austin chalk and Eagle Ford shale at several stations by using metallic analogues. This depth varies from 50 to 400 feet in the area worked.

FIELD EQUIPMENT AND TECHNIQUES

The field equipment contains the essential components of the laboratory equipment (with modifications necessary for field use) plus additional components required to combat 60-cycle noise and to handle heavy currents. Figure 3 is a schematic representation of the circuits. Direct current, obtained from a bank of storage batteries, is passed through a set of parallel-connected mercury relays capable of rapidly opening and closing the circuit. Although the maximum current used in this test was of the order of 5 amperes, a set of mercury relays connected in parallel enables one to use up to about 35 amperes in the transmitting circuit. The current loops for the ground and the model are connected in series so that the same square wave passes through both. A shunt across the

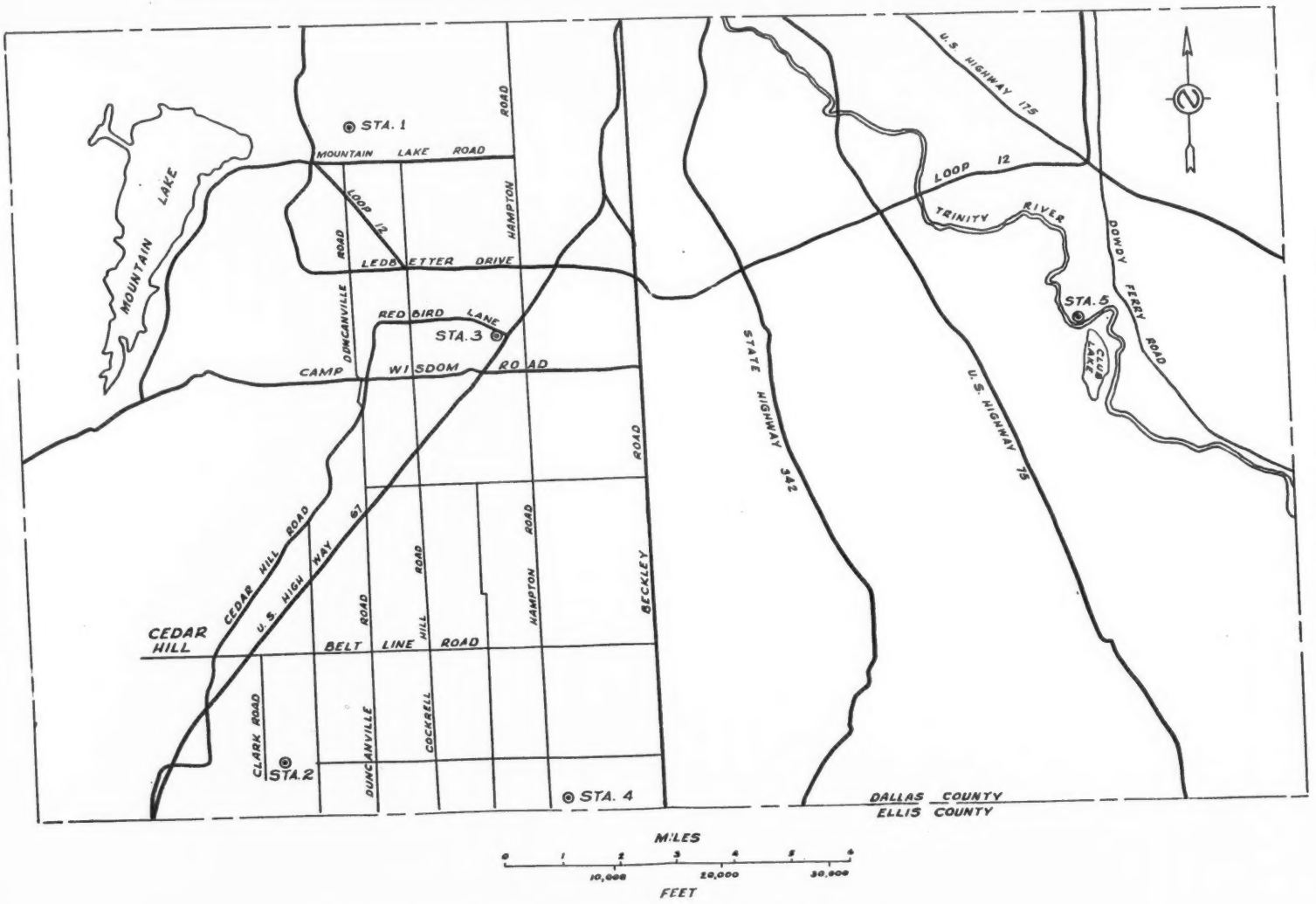

FIG. 2. Map showing location of stations worked in Dallas County, Texas.

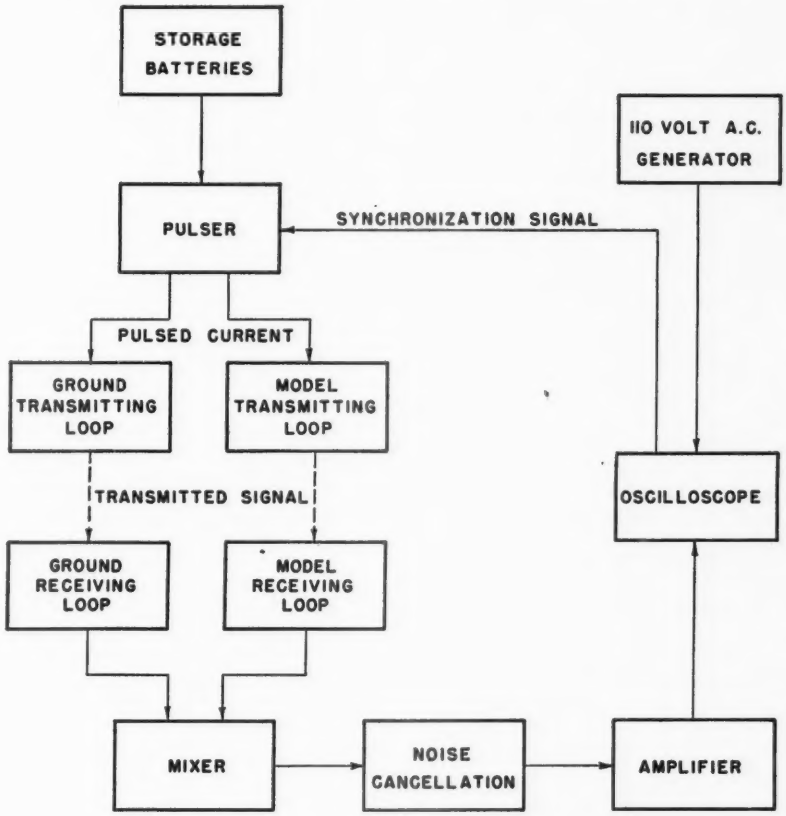

FIG. 3. Schematic diagram of circuits in field equipment.

transmitting loop on the model protects it from destruction by excessive current.

The transmitted signals are picked up by receiving loops corresponding to the two transmitting loops mentioned above—one on the earth and one on the model. These signals are normally mixed in opposition, but a switching device is available so that either signal may be examined separately. Further, the relative amplitudes of these signals may be varied at will through the use of pads in the separate receiving circuits. The output of the mixer is amplified by a pre-amplifier whose high and low cut-off frequencies are 10,000 cps and 1 cps. After pre-amplification, as much noise is removed from the signal as possible. The signal is then amplified to its final value and is displayed on an oscilloscope screen. Synchronization between the oscilloscope and the pulser is accomplished by using the sweep mechanism on the oscilloscope to trigger the pulser. Attention generally is focused only on the part of the signal generated at the beginning of the square wave. Power for the oscilloscope is furnished by a gasoline-powered alternating current generator. Other electronic equipment is battery-operated.

The scheme found most useful for noise cancellation was not described in the

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FIG. 2. Map showing location of stations worked in Dallas County, Texas.

previous papers on these electromagnetic wave studies. In principle, the raw signal is split in a parallel circuit (Fig. 4). In one branch of the circuit only the undesirable noise frequency is allowed to pass; if more than one frequency is troublesome, this side of the circuit must contain as many parallel branches as there are undesirable frequencies. In field work, it has been found that the 60 cps fundamental and its third and fifth harmonics are by far the most troublesome frequencies. In the other branch of the circuit the raw signal is passed directly to a mixer in which a signal having a frequency equal to that of each

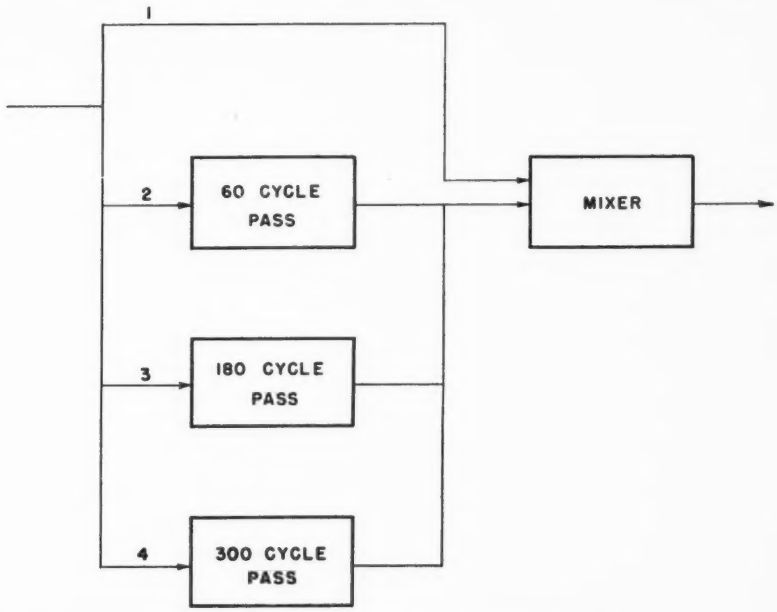

FIG. 4. Schematic diagram for noise cancellation device.

expected component of the noise opposes and cancels the corresponding component of the direct raw signal. The result is the elimination of about 95% of the interference from power lines. Since a hum level of approximately 2% of the total signal was tolerable during operations, an original level of about one-half of the total ground signal could be tolerated. In general, a separation of one-half mile from a 2200-volt transmission line seemed sufficient to fulfill this condition.

The transportation for the field equipment consists of a one-ton truck, a $\frac{3}{4}$-ton pick-up truck, and a $\frac{1}{2}$-ton closed trailer. The electronic equipment is permanently mounted in the panel truck (Fig. 5). Sufficient space remains for the metallic model and storage of a wide assortment of 12″ square plates. Originally, the storage batteries were located under benches inside the panel truck. However, excessive pick-up in the measuring circuits necessitated moving the batteries into the trailer. The 110-volt generator is also mounted in the trailer. The wire and necessary motor-driven reels are mounted in the pick-up truck.

FIG. 5. Inside view of instrument truck showing model in position.

After the appropriate size and separation of the loops on the ground have been determined, the corners are surveyed with a transit and stadia and stakes are set. Normally, the loops can then be laid directly from the reel truck. In the case of rugged or heavily wooded terrain, it is sometimes necessary to lay some sections of the cable by hand. The cable is retrieved in a manner similar to that by which it was laid.

A metallic analogue of the layered earth is constructed, by trial and error, in the field. The closest analogue will yield the most complete cancellation of the signal from the earth by the signal from the model; as a compromise between accuracy and practicability, 99% cancellation is considered satisfactory. When the best model has been constructed, a DuMont Polaroid Land Camera is generally used to photograph three signals displayed on the oscilloscope: 1) the raw signal from the loops on the ground, 2) the best cancellation, and 3) the current square wave for calibration. In some cases, certain other recorded signals may be desired.

Often, a single earth layer is represented in the model by a sandwich of thin plates chosen from the available stock of plates of various resistivities and thicknesses. The resistivity of such a sandwich is defined as the reciprocal of the average conductivity of the sandwich. This definition is necessary in certain cases when some of the layers of the sandwich are nonconducting. The validity of this definition in such cases has been verified in laboratory model work.

SOURCES OF ERROR

Many possible sources of error are introduced when the models are taken from the laboratory into the field. An obvious complication might arise from any topographic relief within the area covered by the loops on the ground. Two laboratory experiments have been performed to throw some light on this source of error. In one otherwise homogeneous aluminum model, a square groove 0.125 inch deep was cut in the surface. When the axis of the coils was oriented along the axis of this groove, the signal was nearly cancelled by placing a horizontal bakelite layer 0.059 inch thick on the surface of a second aluminum model. A triangular groove 0.125 inch deep similarly oriented was modelled by a 0.044 inch bakelite layer on the top of the second model. Several unsuccessful attempts were made to model the groove with horizontal plates when the groove was oriented differently with respect to the axis of the coils.

The second set of laboratory experiments was designed to illustrate the effect of dipping beds but serves equally well to throw some light on the effect of a sloping ground surface. Two wedge-shaped blocks were cut from the same piece of aluminum and were machined into identical wedges which fitted together to form a rectangular plate 1 inch thick. This combination had the effect, when substituted for one of the regular aluminum plates, of introducing a dipping insulating contact into the model. The insulating effect was due to the presence of a comparatively high-resistance, oxidized film which formed on the surface of the

aluminum immediately after it was cut. The angle of dip was 10.2 degrees. The residual signal, after removal of the boundary wave caused by this inclined interface depended upon the orientation of the coils with respect to the strike of the inclined contact. When the axis of the coils was oriented along the strike, the reflected signal had the same polarity as the signal due a layer of high-resistivity material at depth; if the axis was oriented perpendicular to the strike, the polarity became that which would be caused by a low-resistivity material at depth. Attempts to cancel these residual signals to within less than about 10% (which is comparable to 1% cancellation of the total signal) by using horizontal layers in the second model were unsuccessful. In a similar experiment, a single wedge was placed on top of a stack of parallel aluminum plates, the purpose being to investigate the effect of a sloping ground surface. Once again, a "reflected" signal was superposed on the boundary wave and could not be successfully cancelled by signals from a model constructed only of parallel plates.

We learn from the experiments just described that one cannot generally expect exact cancellation of signals from the earth by signals from a model constructed of horizontal metallic plates, the reason being that relief on the surface and slightly dipping beds are the rule rather than the exception in nature. Since the residual signals shown above are normally a small fraction of the total observed signals and since cancellation of these spurious signals could usually be accomplished within about 10%, it is felt that one could reasonably expect to get cancellation of about 1% of the total signal.

In all our experiments, the modelling is restricted by the minimum available thickness of the plates, usually of the order of 0.020 inch. In some instances foil 0.001 inch thick was used on the surface of certain models. An even more severe limitation applies to the number of materials of different resistivities which are available for use in the model.

It has been found that the best results are obtained when the coil separation is of the same order of magnitude as the depth of the interface being examined; further, the ratio of the coil diameters (from the model and the earth) should be approximately equal to the ratio of the coil separations. It is felt that further investigation will reveal that there is some sort of "focusing effect" and that there is an optimum loop geometry for each geologic problem.

RESULTS

In Figure 6 are shown the type of data obtained and the interpretation of the data. The data were taken at a location where subsequent drilling has proven the Austin-Eagle Ford contact to be at a depth of 311 feet. Loops 245 feet square were placed 735 feet from center to center and a square wave was passed through the transmitting loops at a repetition rate of 28 cycles per second. Only the "make" of this square wave is shown (Fig. 6c). The principal purpose of this record is to furnish a calibration for the other signals recorded. When the "make" occurs in the transmitting loop, a signal is induced in the receiving loop (Fig.

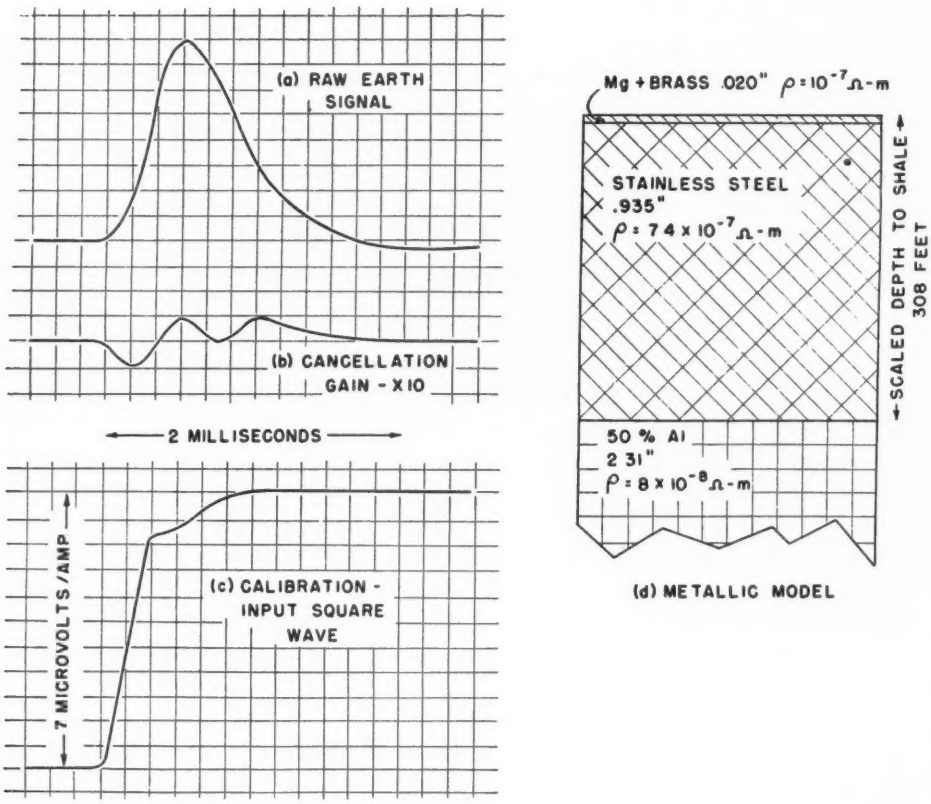
(a) RAW EARTH SIGNAL
(b) CANCELLATION GAIN - X10
2 MILLISECONDS
7 MICROVOLTS/AMP
(c) CALIBRATION - INPUT SQUARE WAVE
Mg + BRASS .020" ρ = 10⁻⁷ Ω-m
STAINLESS STEEL .935" ρ = 7.4 x 10⁻⁷ Ω-m
50 % Al 2.31" ρ = 8 x 10⁻⁸ Ω-m
SCALED DEPTH TO SHALE 308 FEET
(d) METALLIC MODEL

FIG. 6. Results obtained at location 4 showing type of data used in modelling experiments.

6a). These two signals are displayed here at the same gain. The best cancellation which was obtained is shown on the third trace (Fig. 6b).

The validity for modelling the earth, if displacement currents are assumed not to exist, lies in the condition (Stratton, 1941, p. 488–490) that

$$\frac{R_e^2 f_e \mu_e}{\rho_e} = \frac{R_m^2 f_m \mu_m}{\rho_m} \tag{1}$$

where R is a length, f is frequency, μ is magnetic permeability, and ρ is resistivity. The subscripts "e" and "m" refer to the earth and the model respectively. In using this relationship, we assume that the magnetic permeabilities for both the earth and the model are unity. Since the transmitting loop for the earth and that for the model are connected in series, the two frequencies are the same. Therefore, equation (1) reduces to:

$$\frac{R_e}{R_m} = \sqrt{\frac{\rho_e}{\rho_m}} = K \tag{2}$$

TABLE I. DATA FROM EARTH MODELLING EXPERIMENTS IN DALLAS COUNTY, TEXAS

Station	Metallic Model					Modelled Earth			Relief within Loops (feet)	True Mean Depth of Austin-E.F. Contact (feet)	Ratio of Relief to Depth	Error in Depth Determination (%)	Degree of Cancellation (%)
	Metal	Thickness (inches)	Depth to Top (inches)	Resistivity (micro-ohm-meters)	Scaling Factor (feet/inch)	Thickness of Formation (feet)	Depth to Formation (feet)	Resistivity					
1	Al	.006		.045	639	4		2.6					
	85% Brass*	.088	.006	.12		56	4	7.1					
	Al	1.500	.094	.045		960	60	2.6	13	52	.25	15.4	99.0
2	SS†	.412		.74	329	136		11.5					
	60% Mg	2.117	.412	.15		693	136	2.3	32	140	.23	2.9	99.5
3	Al	.004		.045	406	2		1.1					
	SS†	.472	.004	.74		191	2	17.5					
	Mg	2.000	.476	.090		816	193	2.2	21	189	.11	2.1	98.0
4	Mg.	.018											
	Brass	.002		.091	322	6		1.4					
	SS†	.935	.020	.74		302	6	11.0					
	50% Al	1.300	.955	.090		418	308	1.3	27	311	.087	1.0	99.0
5	‡ 58% SS†	.759		.48	314	238		6.8					
	‡ 28% Bakelite												
	‡ 13% Brass												
	SS†	.270	.759	.74		85	238	10.5					
	14% Mg	.256	1.029	.64		80	323	9.1					
	SS†	.050	1.285	.74		16	403	10.5					
	Mg	1.000	1.335	.090		314	419	1.3	0	402	0	4.2	99.0

* Indicates a "sandwich" of brass plates (85%) and sheets of bakelite (15%). Resistivity given is the reciprocal of the mean conductivity.
† Non-magnetic stainless steel.
‡ Includes .002″ Al at surface. Bakelite is distributed .015″ at depth of .092″ and .205″ at .186″.
$\rho = .045 \times 10^{-6}$ ohm-meters (Al), $.10 \times 10^{-6}$ (Brass), $.090 \times 10^{-6}$ (Mg), to $.74 \times 10^{-6}$ (SS).

where K is the scaling factor. In actual field practice, the scaling factor is determined by taking the ratio of the distance between the centers of the loops on the ground to the corresponding distance for the model loops.

The model used to effect the cancellation discussed above is illustrated in Figure 6d. The material used to represent the limestone or "chalk," as it is usually called, was stainless steel specially prepared to be non-magnetic. In most cases a weathered layer had to be included to effect the best cancellation; a thin magnesium plate and a brass sheet represented this layer. The material representing the low resistivity shale consisted of interposed aluminum and bakelite sheets.

The results obtained at all of the five locations investigated in Dallas County are presented in Table I. The locations of the stations and of the drill holes used for control are shown in the sketch map of the southern part of Dallas County (Fig. 2).

The main object of the study was to determine the depth to the Austin chalk-Eagle Ford shale contact; and, in that respect, the experiment was successful. At the last four stations, where the depth was commensurate with the loop separation, the accuracy varied from 1.0% to 4.2%. Although greater accuracy would be desirable, the precision obtained was satisfactory for an early trial of the method. The depth to the contact at the first location was good only within 15.4%. However, it is felt that this error was due largely to the fact that the depth was too small compared to the size and separation of the loops.

At location 5, the model which was required was considerably more complicated than elsewhere. The reason for this difference may lie in the fact that the station is in the Trinity River bottom land where the chalk is covered by 50 feet or more of Pleistocene and recent alluvium consisting of loose silt and gravel. Moreover, the driller reported considerable variation in his bit reaction at this station, thus indicating that the limestone may be less uniform here than at other locations.

The modelling of earth resistivities was by no means as successful as the determination of depths, although the qualitative contrasts were always well brought out. All of the limestone resistivities had to be modeled at definitely lower values than those measured by electrical logging. Other resistivity determinations are probably low also. One cause, but by no means the only one, of this discrepancy lies in the very limited number of different materials available for use in the model. If many materials of various resistivities could be made available, the results might be better. Moreover, some refinement of the scaling technique might also lead to better results.

CONCLUSIONS

The electromagnetic reflection method has demonstrated in field trials its ability to determine depths to discontinuities in resistivity as predicted by theoretical studies and subsequent laboratory model experiments. Although the re-

sults of this initial field work have not been as accurate nor as dependable as might be desired, it is believed that electromagnetic reflection techniques offer considerable hope. Further development of this method of prospecting should yield a satisfactory and useful tool for the geophysicist.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. C. J. Halley for conducting the laboratory experiments described herein, to Mr. G. L. Hoehn for designing and building the noise elimination device and for furnishing counsel in other pertinent matters, to Drs. J. E. White and R. L. Caldwell for their cooperation and advice during the course of the project, and to the management of Magnolia Petroleum Company for permission to submit this paper for publication.

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GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 490–508, 24 FIGS.

GEOPHYSICAL HISTORY OF MAMOU FIELD, EVANGELINE PARISH, LOUISIANA*

D. RAY DOBYNS† AND W. B. ROPER‡

ABSTRACT

This paper presents a chronological historical record of the geophysical activity in the area near the town of Mamou, Louisiana which subsequently led to the discovery of the Mamou Oil Field.

The successive stages of geophysical exploration were:

1. Mechanical seismograph refraction survey by North American Exploration Company (German company) in August 1926 for Magnolia-Union Sulphur-Harry Hanszen.
2. Torsion balance survey by Shell Oil Company in 1934.
3. Magnetometer survey by Atlantic Refining Company in 1936.
4. Torsion balance survey by Atlantic Refining Company in 1936.
5. Gravity meter survey by Magnolia Petroleum Company the latter part of 1942 and early part of 1943.
6. Three weeks' seismic work by Petty Geophysical Engineering Company for Magnolia Petroleum Company in June 1943.
7. A few weeks' work by General Geophysical Company for Cities Service Oil Company in June, 1943.
8. Detailed seismic survey by Independent Exploration Company for Magnolia Petroleum Company from November, 1943 to June, 1945.

The discovery well, Magnolia's No. 1 J. B. Morein, was completed December 28, 1945 through perforations from 11,520 feet to 11,530 feet, producing 208 barrels of 46.3 gravity oil and 770 MCF gas per day through 8/64 inch choke.

There are three producing horizons in the upper part of the Wilcox group. The first, or Morein stringer, is approximately 5 feet thick and lies about 18 feet above the second, or Morein sand, which has 19 feet average production thickness. The third, or Deshotels sand, has an average productive thickness of 10 feet and is approximately 230 feet below the Morein sand.

Twenty producers and five dry holes were drilled. The field has been unitized and is being waterflooded.

Total production of the field to January 1, 1954 was 2,498,373 barrels. December, 1953 production was 20,604 barrels.

The Mamou Field is located in Township 5 South, Range 1 East in south central Evangeline Parish, Louisiana as shown on the index map, Figure 1.

Figure 2 shows the results of a refraction survey which was conducted in this area by North American Exploration Company in 1926 for Magnolia-Union Sulphur-Harry Hanszen. This was a German company and the old mechanical seismograph was used. Distances from shot to detectors were of the order of two to four miles. Primary arrivals were only obtained from the "first underlayer" and depths computed to this layer. Of course the purpose of the work in these early days of seismograph work was to find piercement type salt domes. Depth values shown are average depths along the lines of shot to seismograph recorders of the first velocity underlayer.

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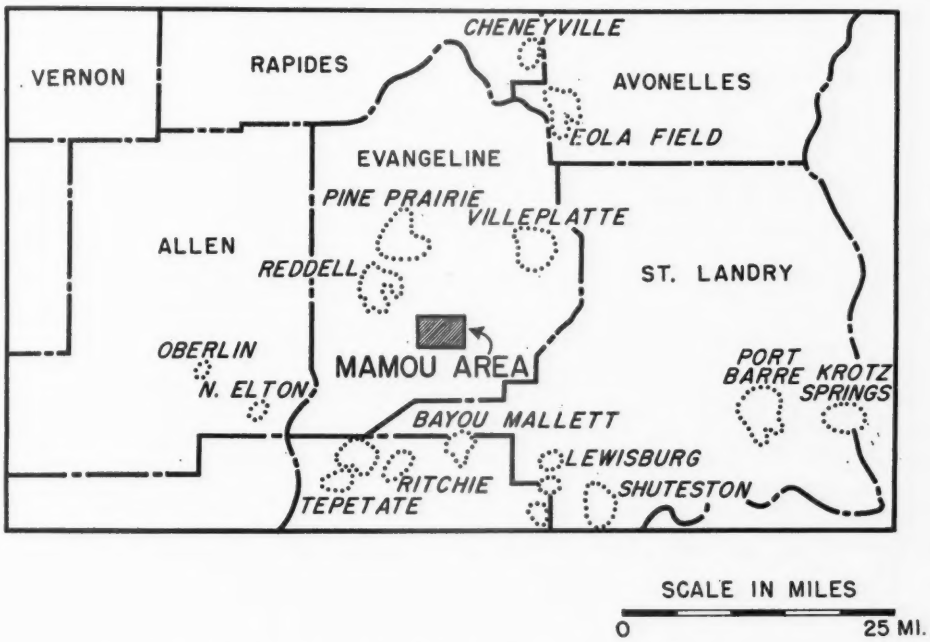

FIG. 1. Index map of portion of South Louisiana showing location of Mamou Area. Dotted lines outline major producing areas.

GRAVITY AND MAGNETIC SURVEYS

Figure 3 depicts the results of a torsion balance survey made for the Shell Oil Company in 1934 by a Schlosser geophysical survey crew with Mr. Prieu as party chief. Only the gravity gradients are shown. The station location is at the opposite end of each line from the arrowhead. The station spacing had about the usual density for that time. It can be seen, however, that more data were needed in Sections 7, 16, 17, and 18. Note the sudden decrease in gradient and slight reversal in the south half of Sections 34 and 35, Township 4 South, Range 1 East and the gradient decrease in the north half of Sections 5 and 6, Township 5 South, Range 1 East.

In Figure 4 the results of a magnetometer survey are portrayed in the south portions of Township 4 South, Range 1 East and 1 West. A part of this magnetic work was done by the Atlantic Refining Company crew with John Moir as Party Chief in 1936–1937 and a portion was done by the R. H. Andrews Geophysical Service, with Morris Jenkins as Party Chief, for the Atlantic Refining Company during the same period of time. The contour interval is 5 gammas with every 25-gamma line emphasized. The small circles indicate the location of the magnetic stations. The station frequency here is about 1.3 stations per square mile.

A rather sharp magnetic maximum appears in Sections 27, 28, 39, and 40, Township 4 South, Range 1 West. This maximum is adjacent to a corresponding

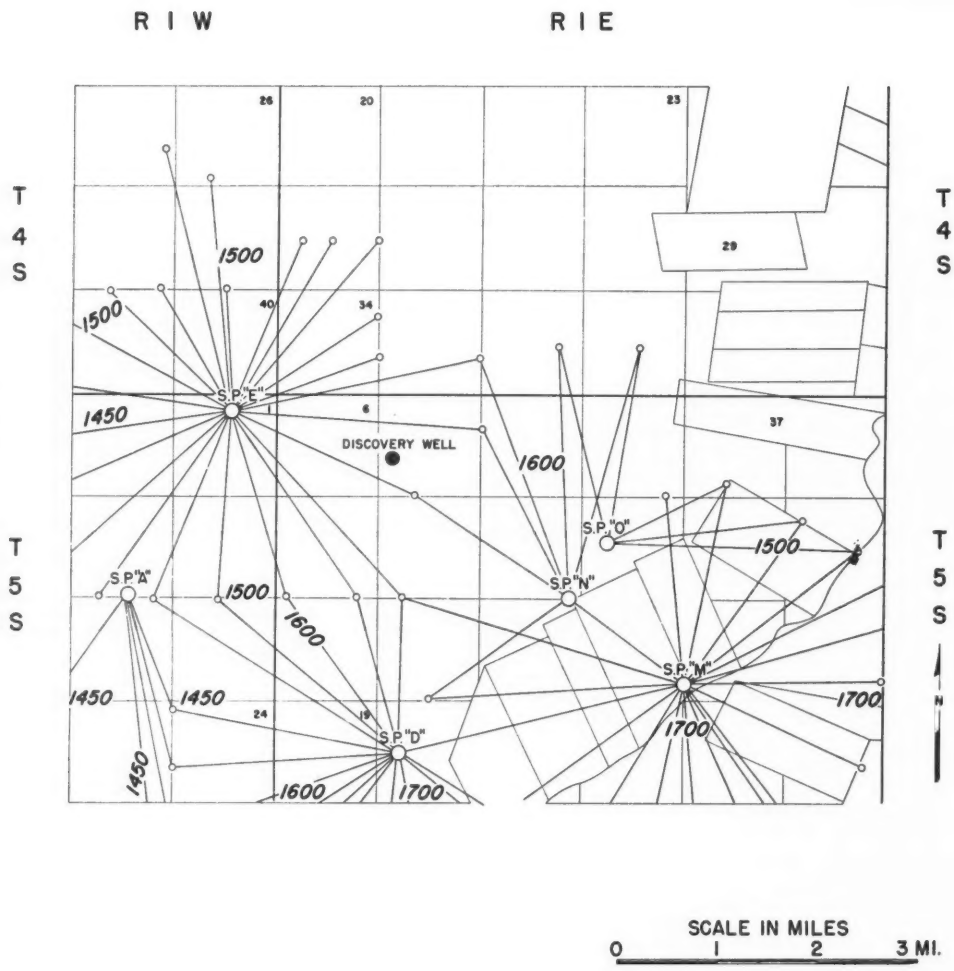

FIG. 2. Mechanical seismograph refraction survey for Magnolia-Union Sulphur-Harry Hanszen by North American Exploration Company, August, 1926. Values along shooting rays are average depths to first velocity underlayer.

sharp magnetic minimum just to the east in Sections 32, 33, 34, and 35, Township 4 South, Range 1 East.

In Figure 5 we have the results of a torsion balance survey run for the Atlantic Refining Company in 1936–1937. This work was done by R. H. Andrews Geophysical Service with Morris Jenkins as party chief. This map shows the gradient, curvature, and isogals. The contour interval is two Eötvös units. The station location is at the intersection of the gradient and curvature lines.

Note that the torsion balance survey did not extend appreciably into Townships 4 and 5 South, Range 1 East. At the time this survey was obtained the

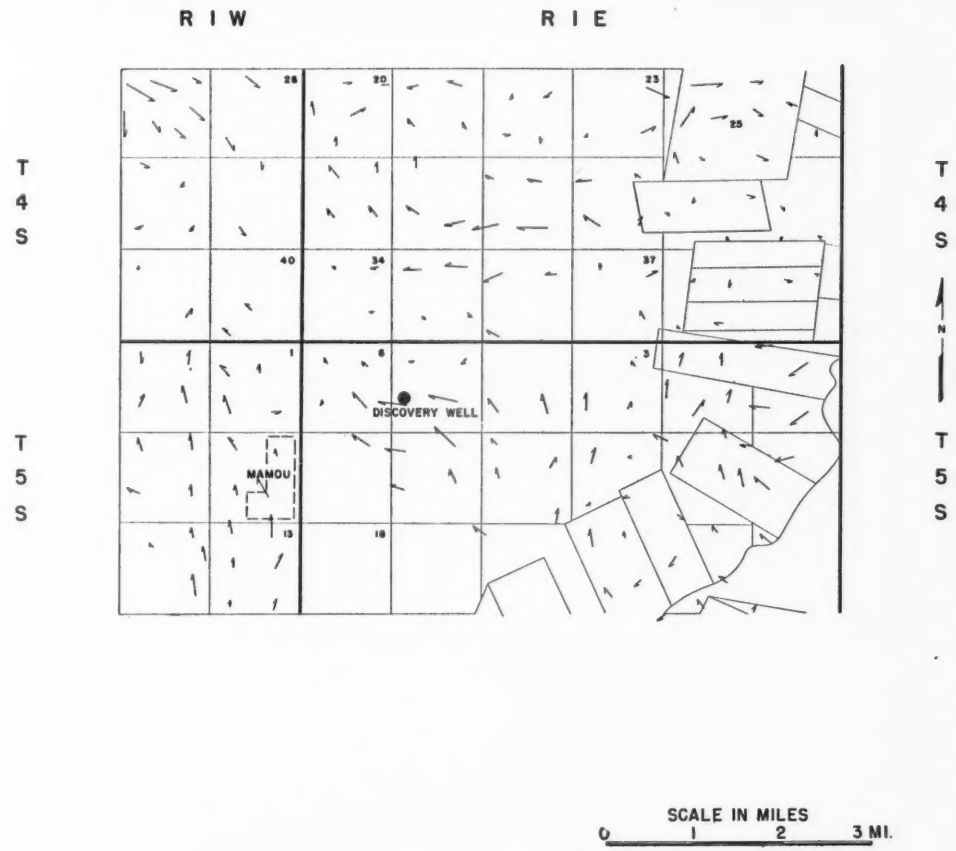

FIG. 3. Torsion Balance gradient map of Mamou Area by Schlosser Geophysical Surveys, for Shell Oil Company in 1934.

Atlantic geophysicists were postulating a possible connection between the coastal salt domes and the interior salt domes through the Pine Prairie area.

Note the gravity maximum just north of the town of Mamou in Section 40. This corresponds to the magnetic maximum shown in Figure 4.

There does appear to be a gravity minimum lead in Section 13, Township 5 South, Range 1 West and in Sections 7 and 18, Township 5 South, Range 1 East.

Figure 6 shows the results of a portion of a reconnaissance gravity meter survey which was run in the Mamou Area by Magnolia Petroleum Company from November, 1942 to April, 1943. This gravity crew was under the direction of W.E. Brogan, Party Chief. The station location is shown by small circles. Isogals are delineated every two-tenths of a milligal with the milligal lines emphasized. Station frequency is approximately 3.3 per square mile.

Two gravity minimum apices appear in the broad minimum anomaly, one about 4 to 5 miles northeast of the town of Mamou and the other about 2 miles

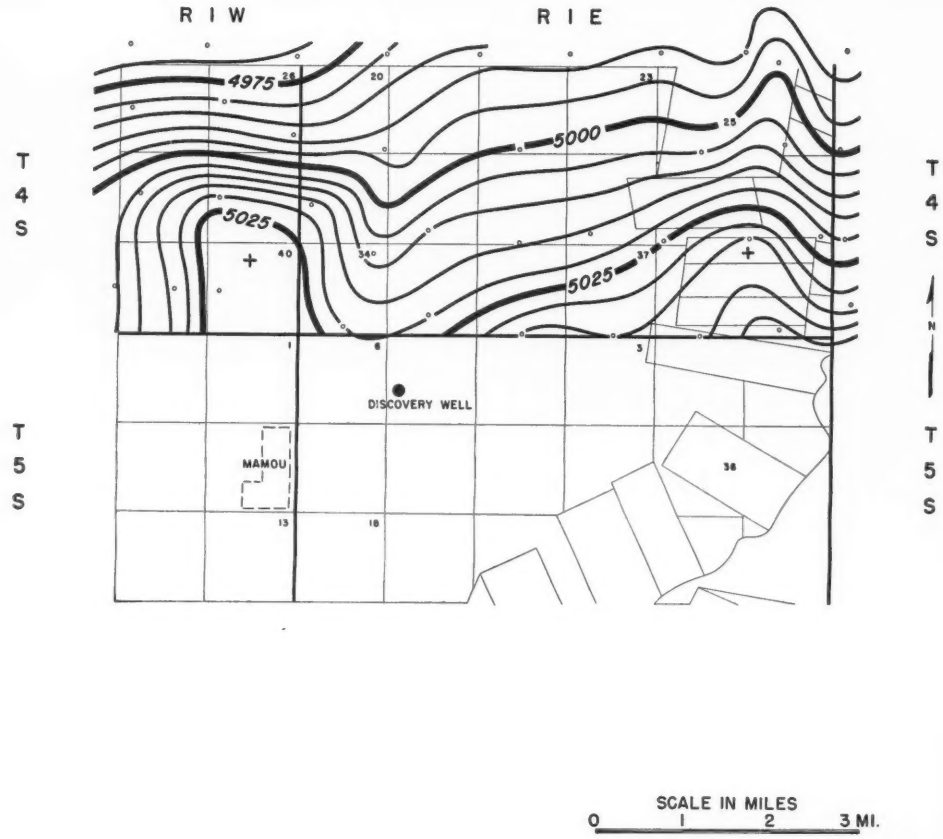

FIG. 4. Map showing results of magnetometer survey, 1936–1937. A part of this work was done by Atlantic Refining Company and part by R. H. Andrews Geophysical Service for Atlantic Refining Company. Contour interval is 5 gammas.

due east of the town of Mamou. Note the maximum closure some 2 miles north of the town of Mamou. This maximum seems to coincide with the previous maxima shown on Figure 4 for magnetics and Figures 3 and 5 for torsion balance.

Figure 7 depicts the residual of the Bouguer gravity shown on Figure 6. The contour interval is two-tenths of a milligal. This residual was prepared from a grid of $1\frac{1}{2}$ mile intervals. Had a smaller grid pattern been used, say one mile, the anomalous conditions would have been emphasized.

Although not shown fully in Figure 7, the actual minimum gravity anomaly immediately east of the discovery well is 4 to 5 tenths of a milligal. Minimum anomalies, giving so-called salt control, were utilized for possible structural interpretation in this area. On the basis of this gravity work, recommendations for leasing were made by the Magnolia Geophysical Department in May, 1943.

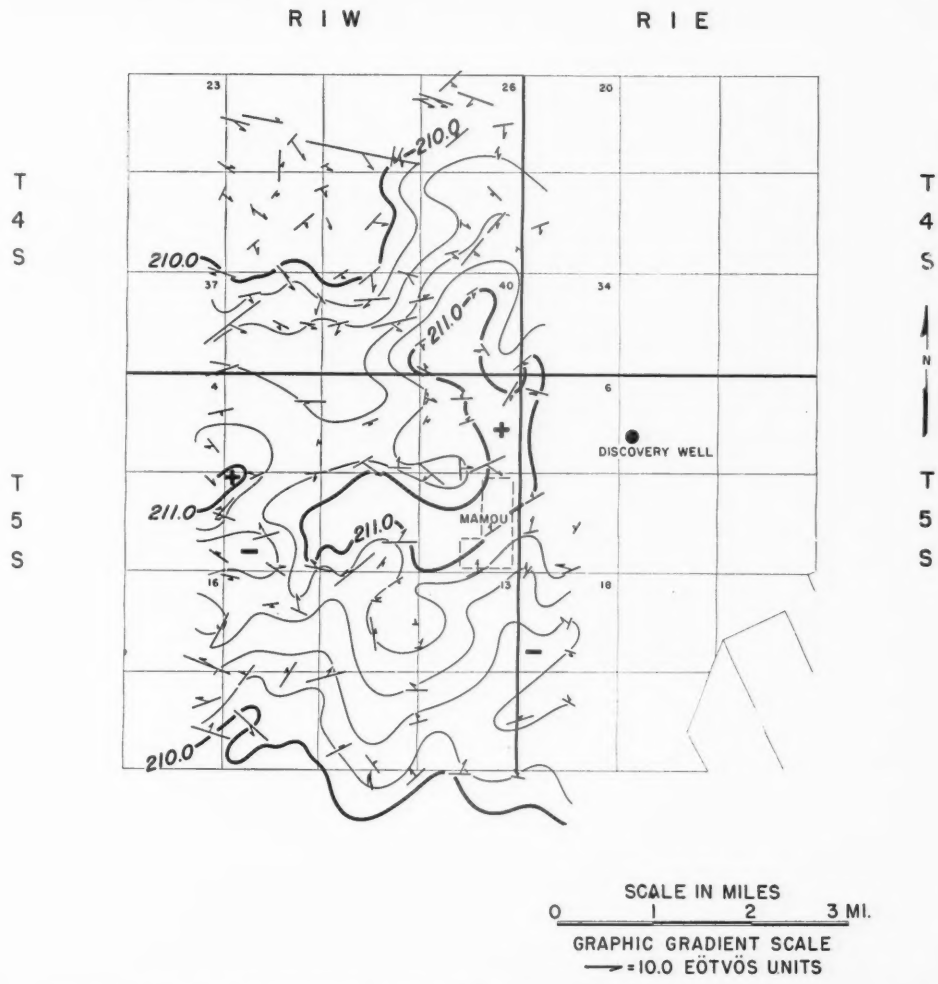

FIG. 5. Torsion balance contour map, by R. H. Andrews Geophysical Service, for Atlantic Refining Company, 1936–1937, showing gradient, curvature, and isogals. Contour interval is two Eötvös units. Station location is at intersection of gradient and curvature lines.

SEISMIC REFLECTION SURVEYS

While this first leasing was in progress in June, 1943, a Petty Geophysical Engineering Company party, under the direction of C. D. Whitsitt, was put into the area to do seismic work for Magnolia Petroleum Company. Figure 8 is a map at approximate Vicksburg depth of the very small amount of seismic work which was done at this time. The continuous profile method of reflection shooting was employed with shot holes spaced at 1,200-foot intervals. Shot holes were drilled to a depth of 45 feet to 75 feet. Best records were obtained at a depth of around 50 feet.

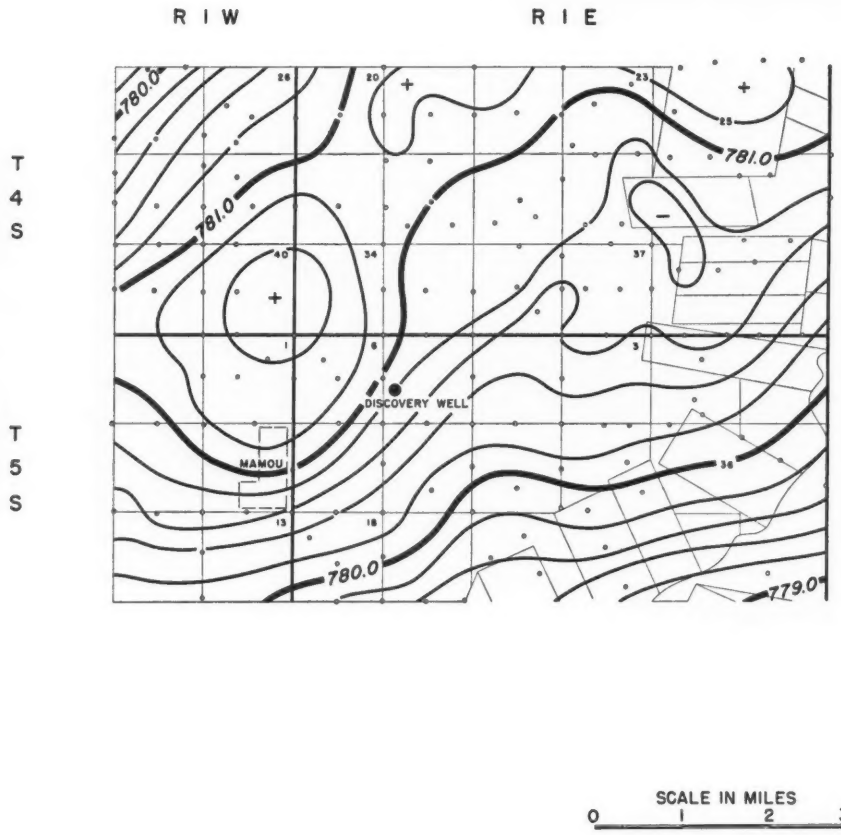

FIG. 6. Gravity meter isogal map by Magnolia Petroleum Company 1942–1943. Contour interval is two-tenths of a milligal.

Time corrections for the low velocity near-surface zone were made by correcting to a datum of 50 feet below sea level by means of the "deviation from normal" method, using a V_1 of 1,500 feet per second and a subweathering velocity of 5,500 feet per second. The first and second detector groups on each side of the shotpoint were averaged for depth points at the shotpoint. A time-depth curve was constructed from a deep well survey of the Bachelor Oil Company's No. 1 Hackney located approximately 40 miles to the east in Pointe Coupee Parish.

Figure 9 is the map at approximate top of Wilcox depth. Figure 10 shows the north-south time section A-A below two seconds. Figure 11 shows the north-south time section C-C below two seconds.

It can be seen from both Figure 8 and Figure 9 that an anomalous condition is present, but certainly more work was needed to assure that the anomaly could be accounted for by faulting and north dip into the fault.

Magnolia found it necessary to use this crew in another area and no more work was done at this time than that shown on these maps. Following this work

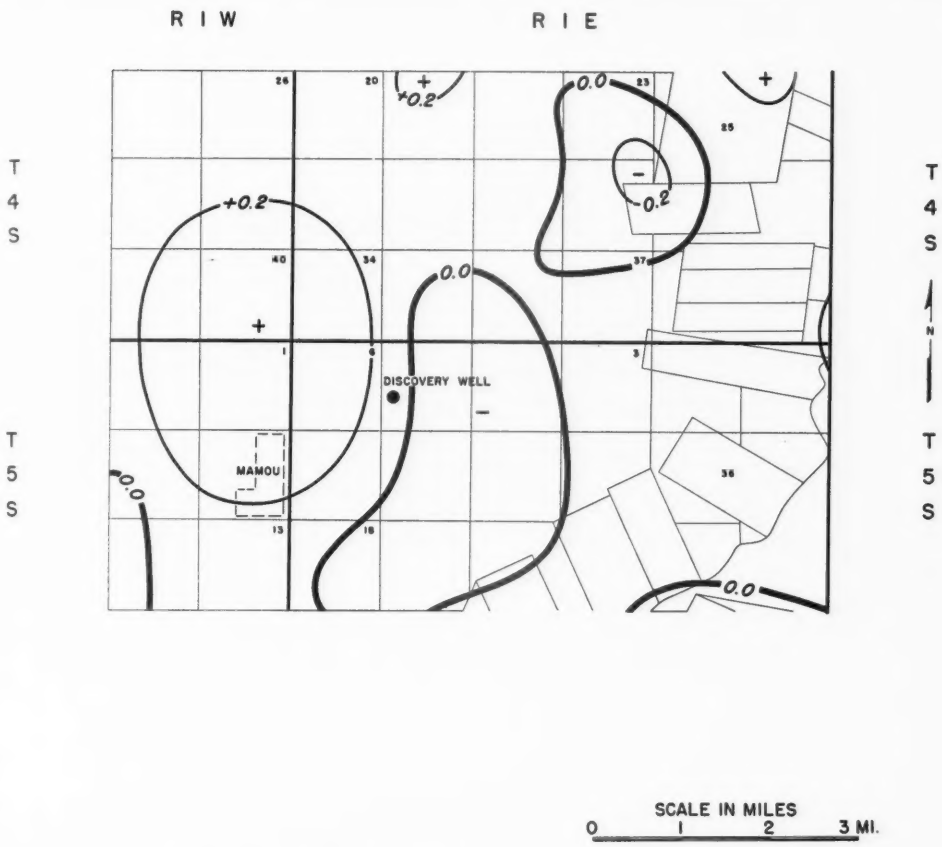

FIG. 7. Residual gravity map from gravity meter survey by Magnolia Petroleum Company, 1942–1943. Contour interval is two-tenths of a milligal.

the outline for leasing was revised on the basis of this small amount of seismic work and the previous gravity meter work.

At approximately the same time, in June and July 1943, some seismic work was being done in this general area for Cities Service Oil Company by General Geophysical Company. Only a small amount of work was done in Township 5 South, Range 1 East. Figure 12 is a map of this work at approximately Heterostegina depth. Continuous profiling was used with seismometer groups spaced at 200 foot intervals and with shotpoints approximately 2,600 feet apart. Uphole corrections were made and an elevation correction velocity of 5,000 feet per second was used. Charge size varied from $2\frac{1}{2}$ lb to 5 lb with hole depths of 40 to 50 feet.

Figure 13 is a deeper map based on a phantom horizon at approximately Vicksburg depth. Figure 14 is a depth cross-section of line A-A′ and Figure 15 is a depth cross-section of line B-B′.

The similarity of the Vicksburg map of Figure 13 to the Vicksburg map of Figure 8 will be noted. Both maps indicated an anomalous condition but Figure

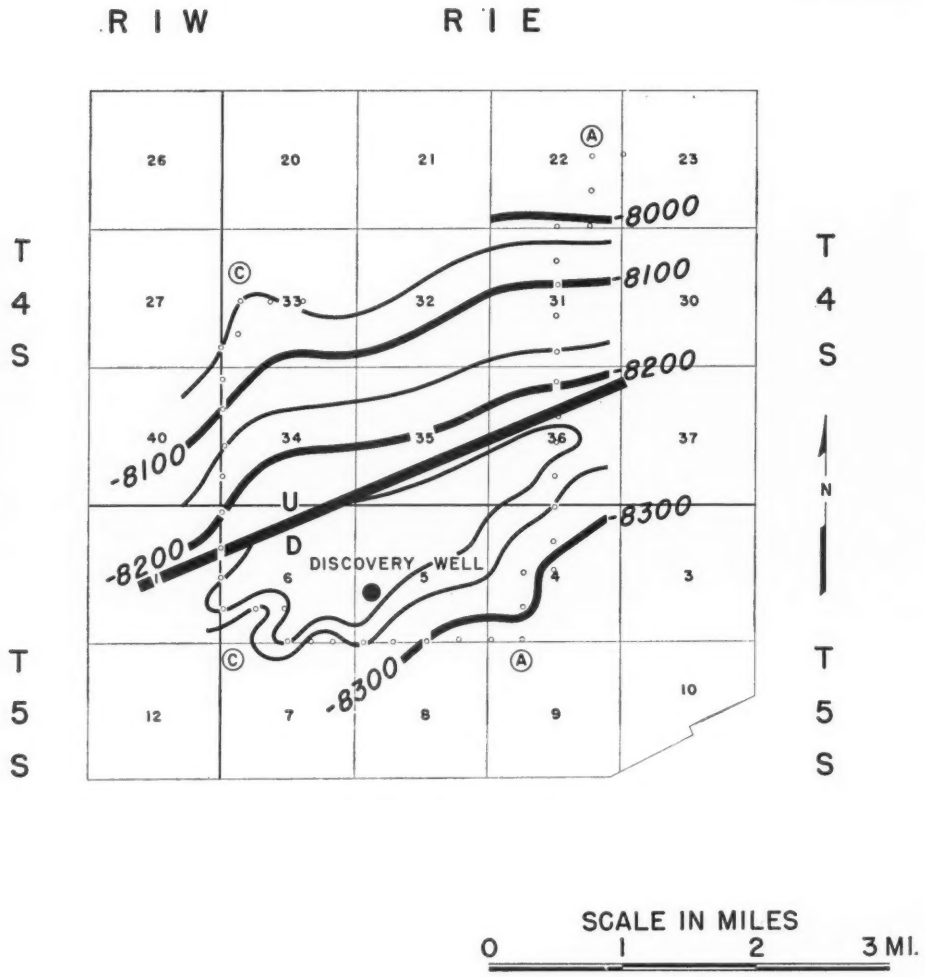

FIG. 8. Reflection seismograph map by Petty Geophysical Engineering Company, for Magnolia Petroleum Company, June, 1943. Vicksburg horizon. Contour interval 50 feet.

13 does not show the possible fault. The faulting at Vicksburg depth, if it is present at all, is of such small magnitude that it is very difficult to see on the seismic records and cross sections.

In November, 1944 an Independent Exploration Company seismic crew under the direction of Donald Crary was put to work in the area by Magnolia Petroleum Company. Figure 16 is a map of this work at Heterostegina depth.

Continuous profiling was used with two detectors per trace and eleven traces. Output mixing was used. The average depth of holes was 50 feet and the average dynamite charge was 15 pounds. An average of seven holes were obtained per day covering approximately 7,184 feet of line.

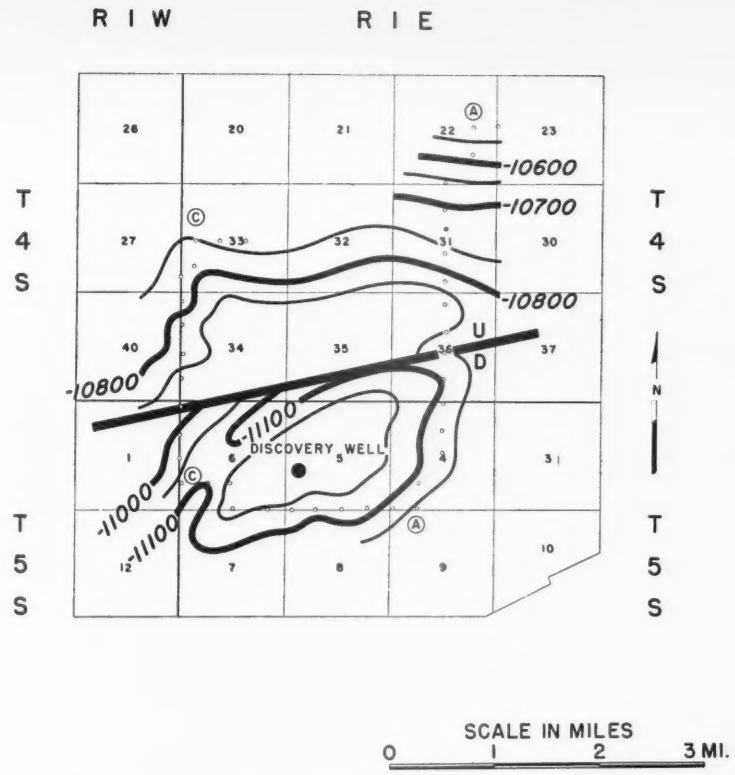

FIG. 9. Reflection seismograph map by Petty Geophysical Engineering Company, for Magnolia Petroleum Company, June, 1943. Wilcox horizon. Contour interval 50 feet. Lines of time cross sections indicated by A-A and C-C.

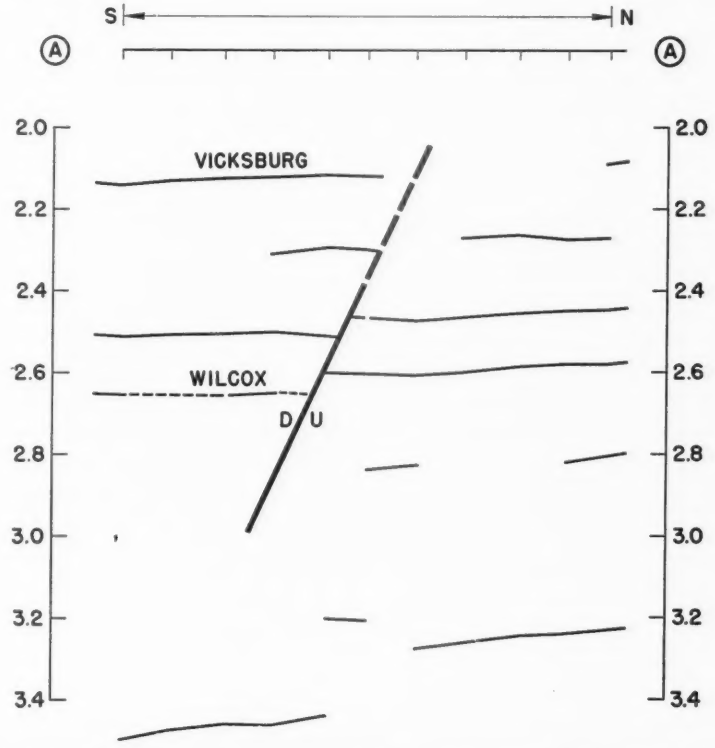

FIG. 10. Reflection time cross-section A-A by Petty Geophysical Engineering Company, for Magnolia Petroleum Company, June, 1943.

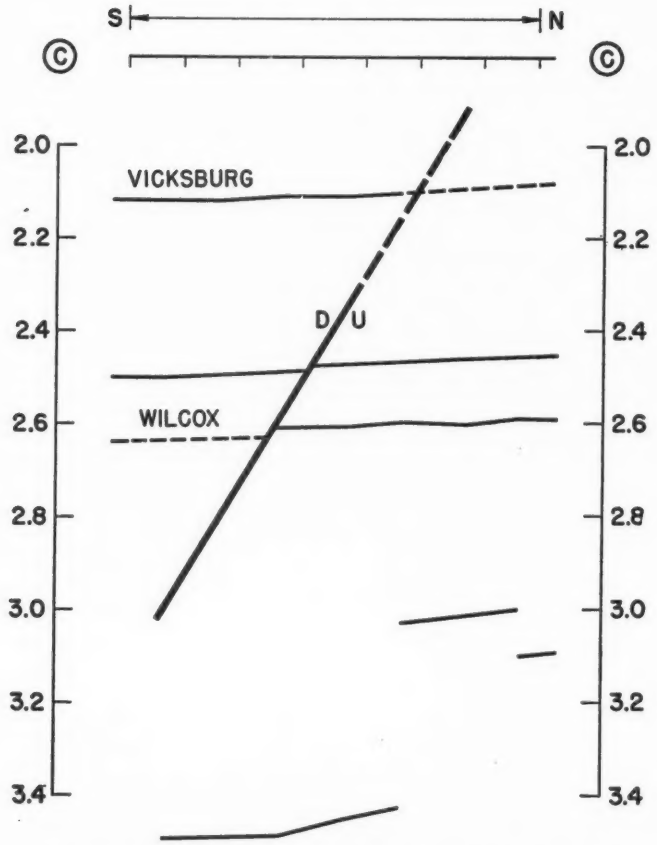

FIG. 11. Reflection time cross-section C-C by Petty Geophysical Engineering Company, for Magnolia Petroleum Company, June, 1943.

The uphole method was used to make weathering corrections and all record times were corrected to a 50-foot datum phone at 5,300 ft/sec.

The Heterostegina reflection was of fair to good quality and had correlatable character throughout the area. Only a small terracing is noted in Sections 1 and 6.

Figure 17 is a map at Vicksburg depth. The Vicksburg reflection was of poor quality and a phantom had to be used over part of the area. A pronounced terracing runs through Sections 4, 5, and 6.

Figure 18 is a map at Wilcox depth. The Wilcox reflection near the top of the Wilcox section was of fair quality but some phantom work was necessary over part of the area. It will be noted that at Wilcox depth the faulting and associated north dip becomes more apparent. The position of the discovery well, the J. B. Morein No. 1, on this map should be noted. Figures 19 through 23 are seismic time sections along A-A, B-B, C-C, D-D, and E-E respectively. Location was made by Magnolia Petroleum Company for the J. B. Morein No. 1 in the C NW¼ SW¼

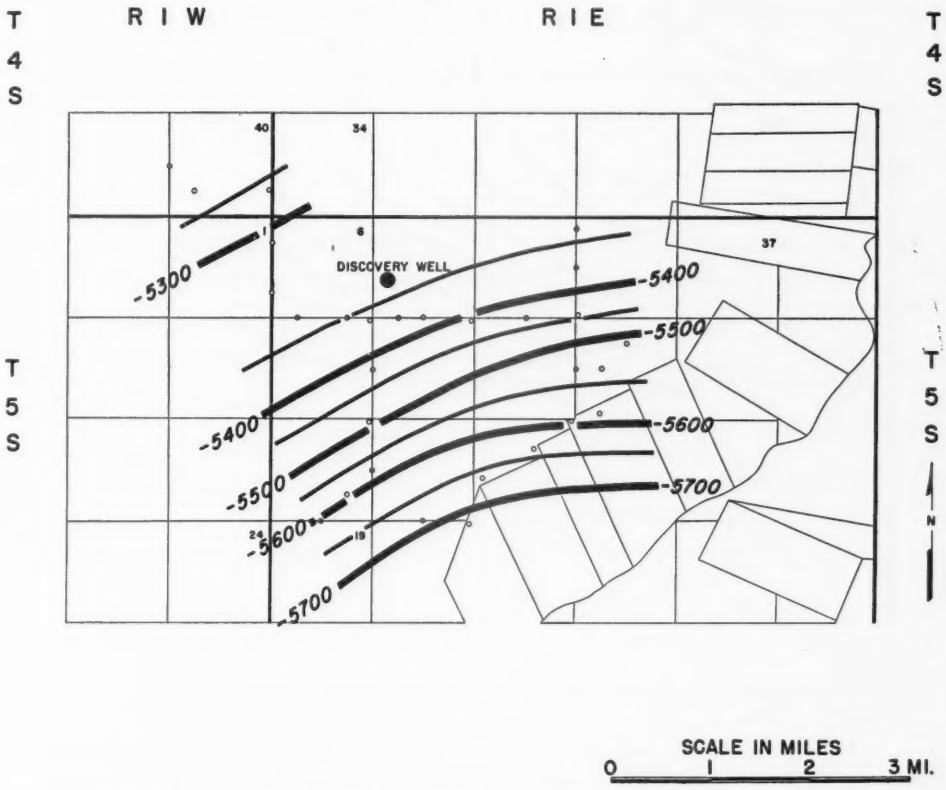

FIG. 12. Reflection seismograph map by General Geophysical Company, for Cities Service Oil Company, June, 1943. "L" horizon (approximately Heterostegina depth). Contour interval 50 feet.

Section 5, Township 5 South, Range 1 East, and drilling commenced in September, 1945.

DEVELOPMENT OF FIELD

This well was completed in December 1945 through perforations from 11,520 feet to 11,530 feet, in what is called the Morein sand of the Wilcox formation, producing 208 bbls of oil and 770 MCF of gas per day, on 8/64 choke, with tubing pressure 3,950 pounds per square inch, casing sealed. Gas oil ratio was 3,700 CF/bbl. Gravity of oil was 46.3 at 60°—A.P.I.

The J. B. Morein sand has an average permeability of 45 md, average porosity of 19.7 percent, and net productive average thickness of 19 feet.

Subsequent to the discovery well, twenty producers in all were completed. Figure 24 is a structural map of the field on top of the Wilcox. The discovery well is the highest well in the field. Twelve wells were completed in the Morein sand; four in the Deshotels sand; and four in the Morein stringer, all in the Wilcox.

The Deshotels sand has an average productive thickness of 10 feet, an average

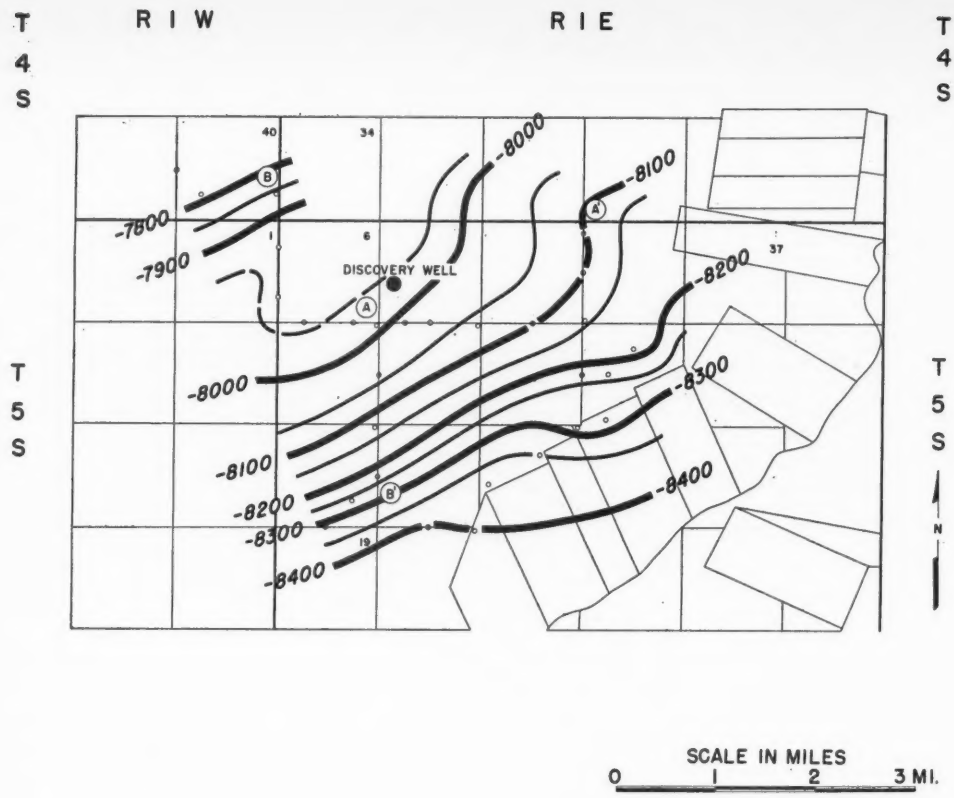

FIG. 13. Reflection seismograph map by General Geophysical Company, for Cities Service Oil Company, June, 1943. "M" horizon (approximately Vicksburg depth). Contour interval 50 feet.

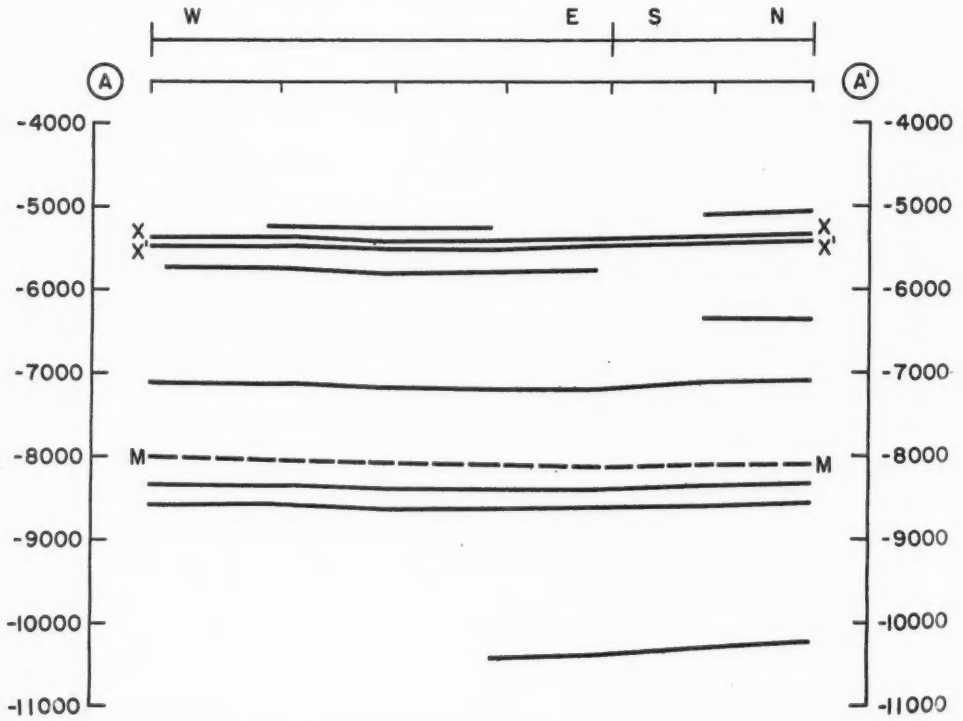

FIG. 14. Reflection depth cross-section A-A′ by General Geophysical Company, for Cities Service Oil Company, June, 1943.

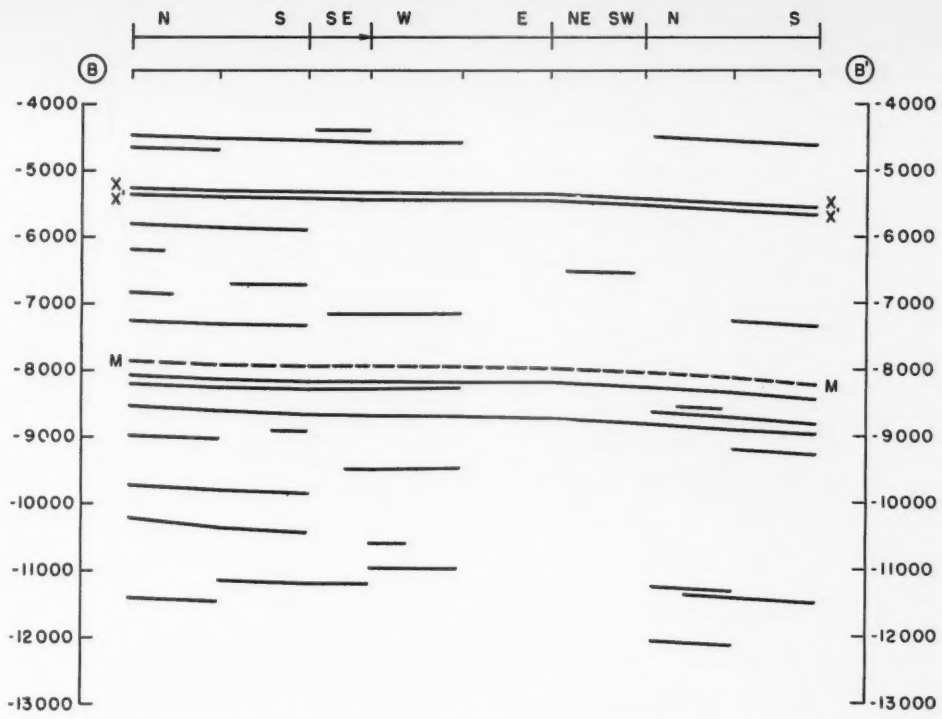

FIG. 15. Reflection depth cross-section B-B′ by General Geophysical Company, for Cities Service Oil Company, June, 1943.

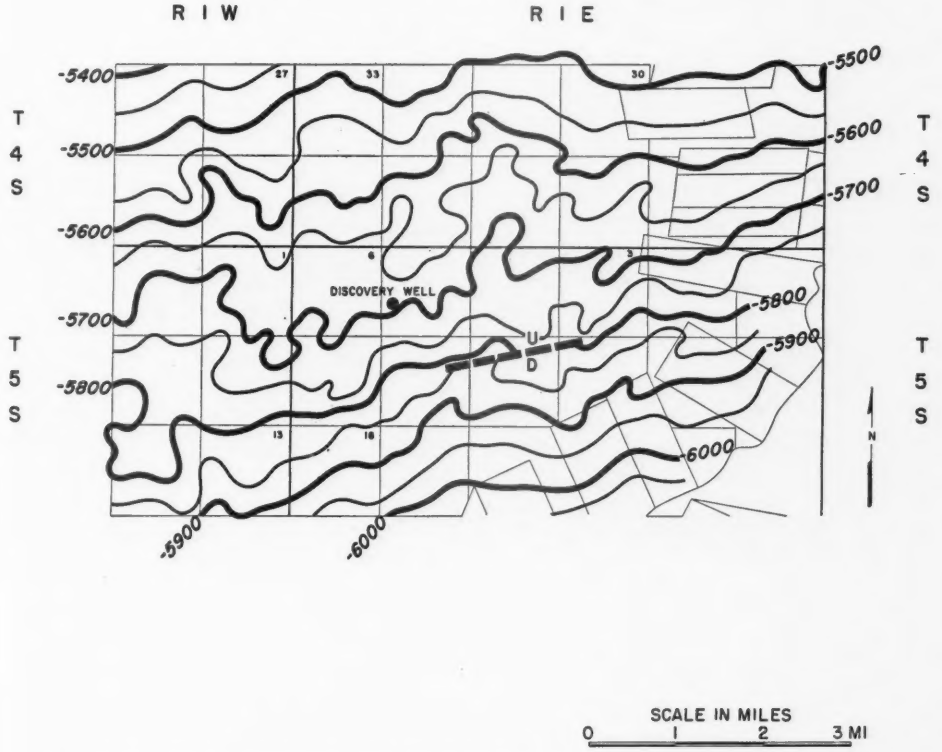

FIG. 16. Reflection seismograph map by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945. "Heterostegina or Marginulina horizon." Contour interval 50 feet.

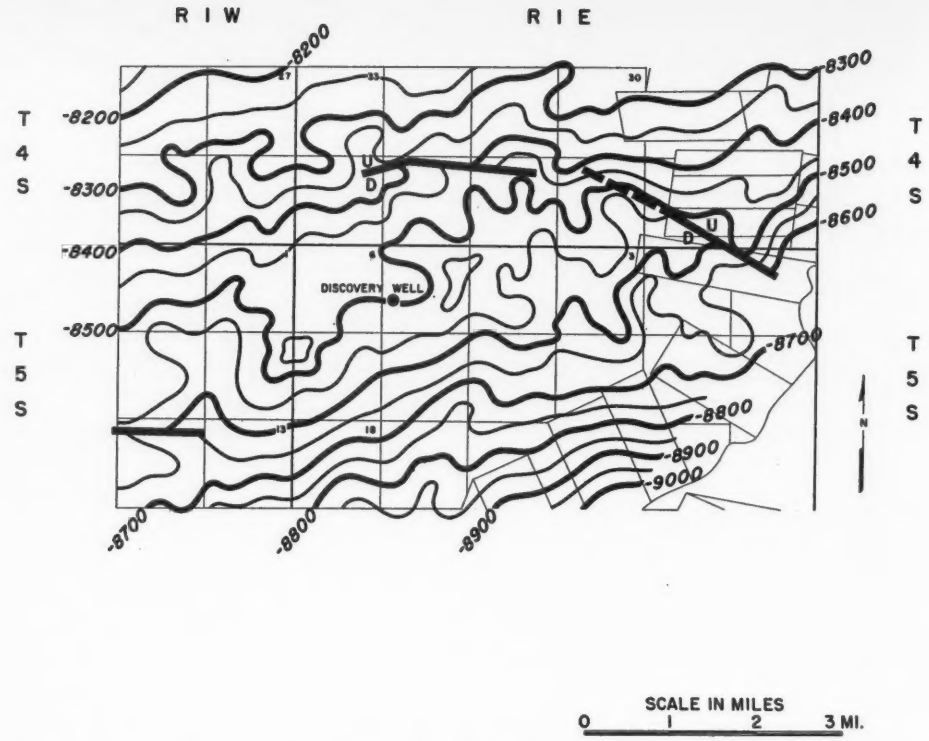

FIG. 17. Reflection seismograph map by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945. Vicksburg horizon. Contour interval 50 feet.

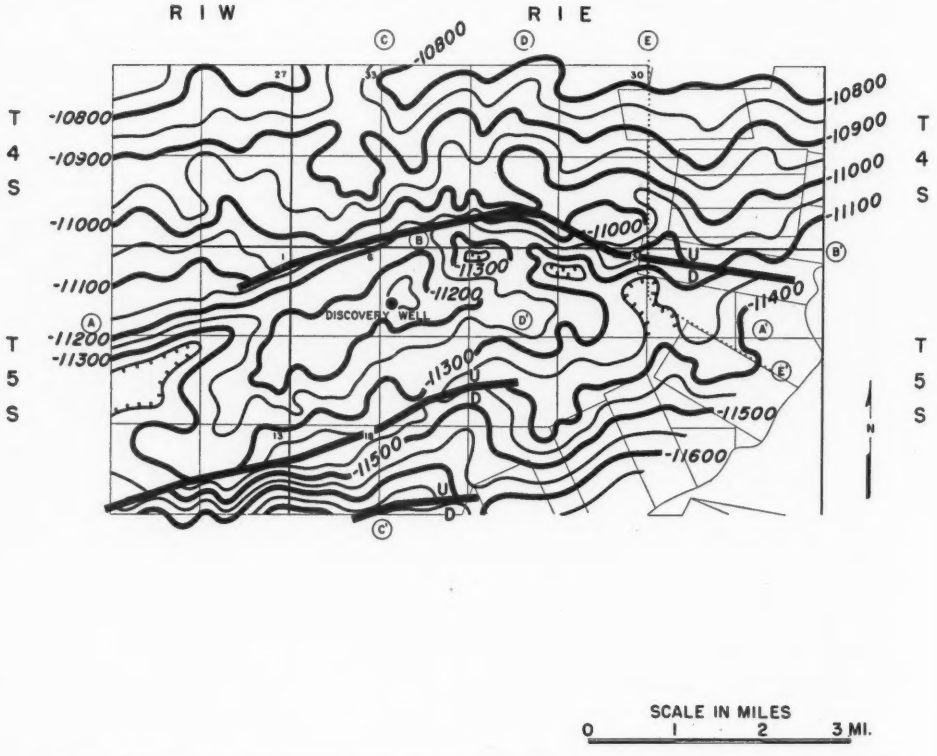

FIG. 18. Reflection seismograph map by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945. Wilcox horizon. Contour interval 50 feet. (Cross-section lines designated A-A, B-B, C-C, D-D and E-E.)

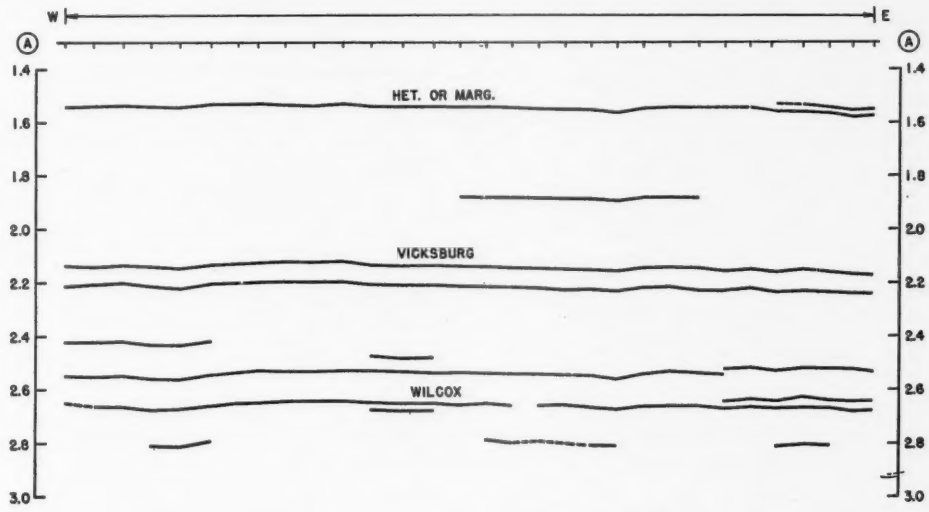

FIG. 19. Seismograph time cross-section A-A by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945.

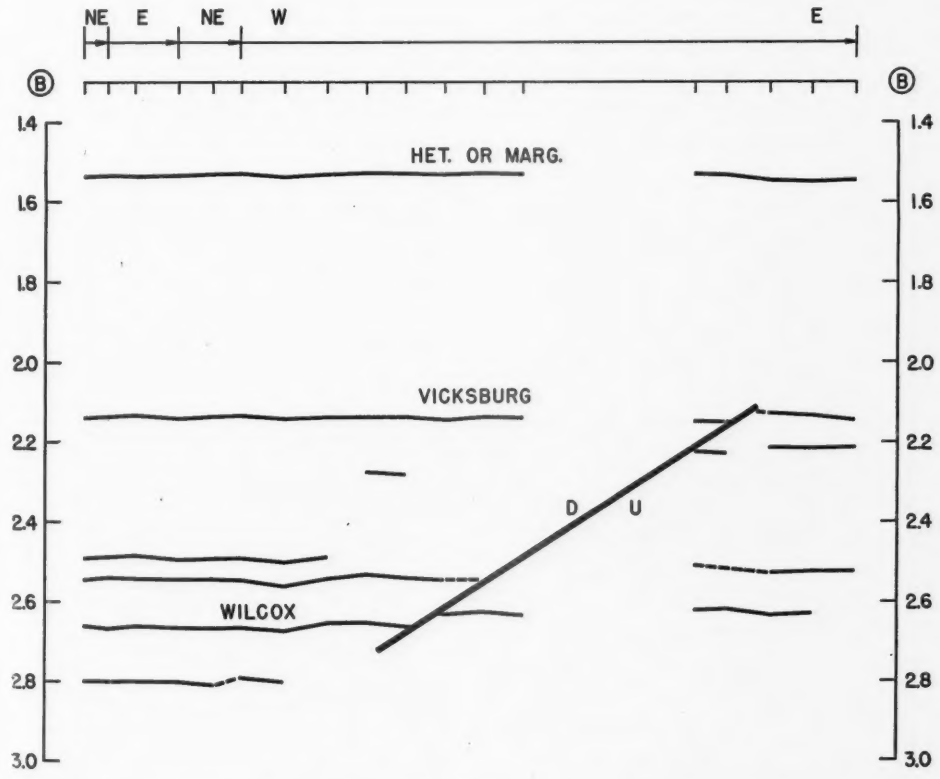

FIG. 20. Seismograph time cross-section B-B by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945.

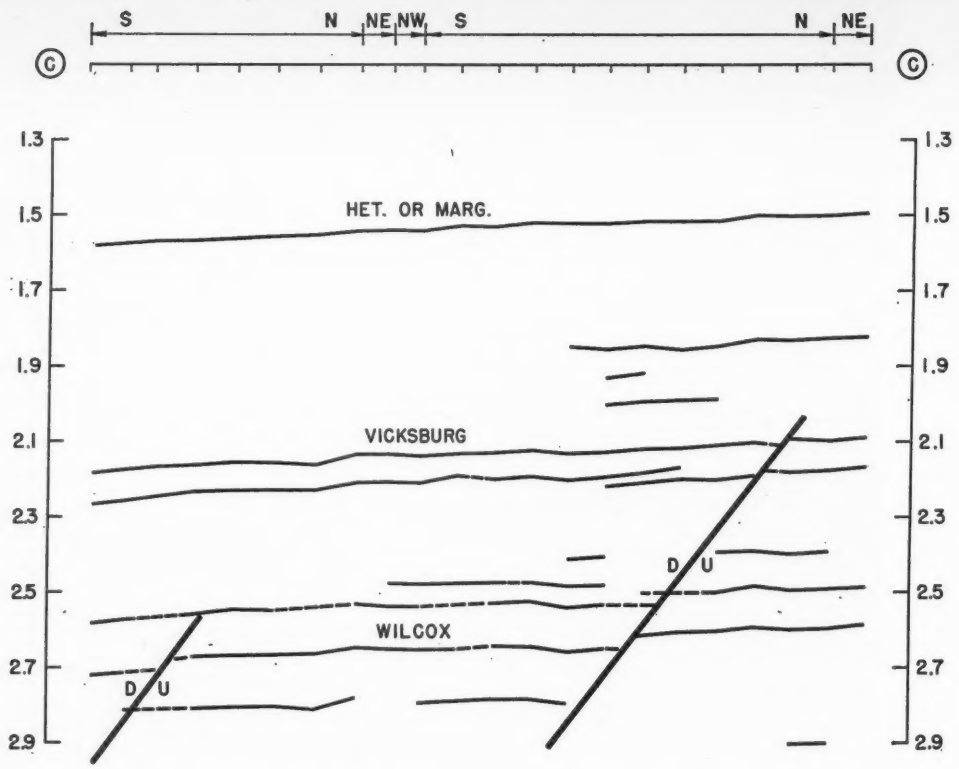

FIG. 21. Seismograph time cross-section C-C by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945.

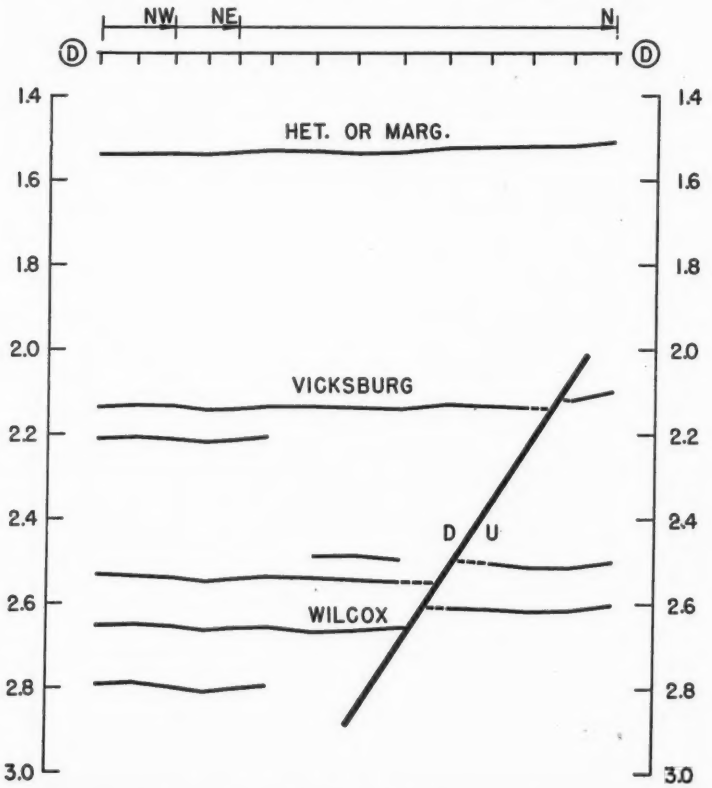

FIG. 22. Seismograph time cross-section D-D by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945.

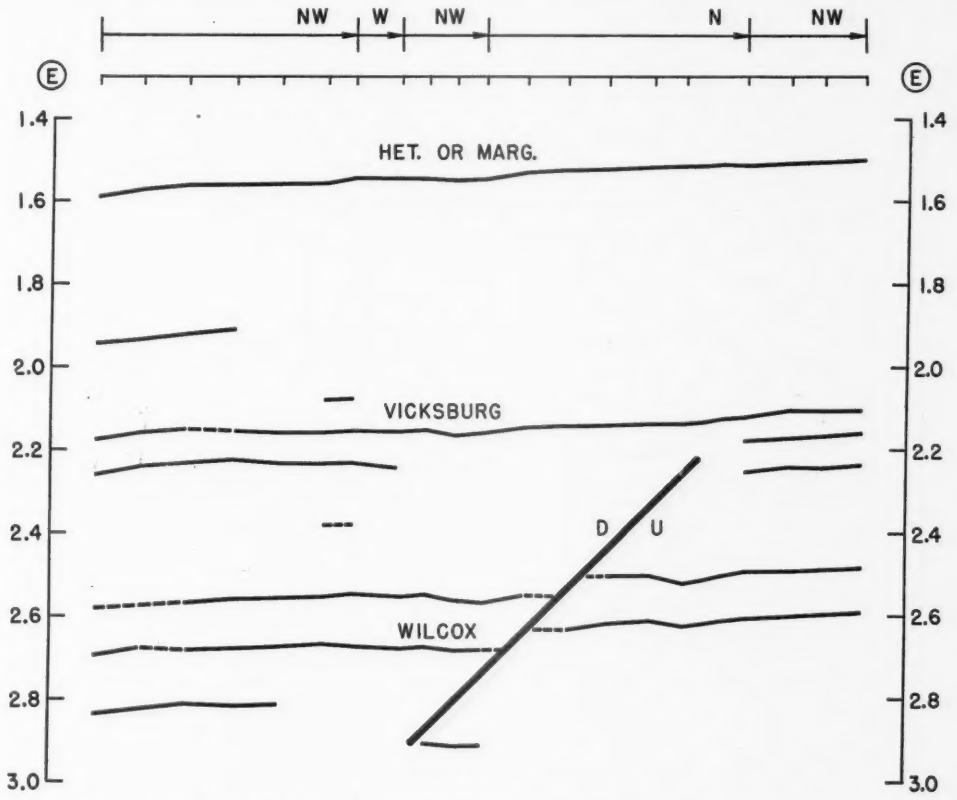

FIG. 23. Seismograph time cross-section E-E by Independent Exploration Company, for Magnolia Petroleum Company, November, 1944 to June, 1945.

permeability of 19 md and an average porosity of 19.3 percent. It lies approximately 230 feet below the Morein sand. The first well completed from this sand was the Magnolia Hilda Deshotels No. I, which was completed August 8, 1946.

The third producing zone is the Morein stringer, approximately 18 feet above the Morein sand. This zone is only about 5 feet thick.

The Magnolia No. I Duos, located in the $SE\frac{1}{4}$ $SW\frac{1}{4}$ Section 6, was drilled to a total depth of 13,800 feet. This well drilled through approximately 2,300 feet of Wilcox with no additional sands which warranted testing.

As of January 1, 1954 two wells had been abandoned. Total production for the field to January 1, 1954 was 2,498,373 barrels. December 1953 production was 20,604 barrels. Five dry holes were drilled but these are not a total loss as some of these are being used for the unit water flood which was started February 16, 1949.

CONCLUSIONS

An examination of the subsurface structural map of Figure 9, the Wilcox map based on the first small amount of seismic work done for Magnolia Petroleum Company, shows that a location based on this map would have found the field.

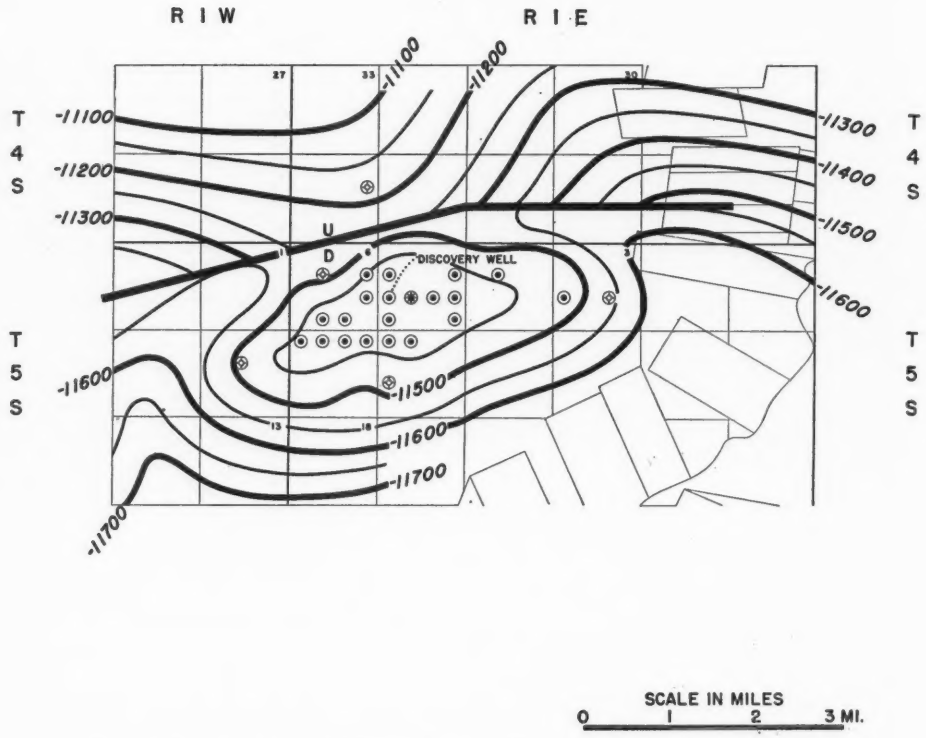

FIG. 24. Structural map of Mamou Field on "Top of Wilcox" by Magnolia Geological Department, 1951. Contour interval 50 feet.

It is hardly to be expected, however, that anyone would have drilled a 12,000-foot test on such a small amount of work. Figure 18, the Wilcox map based on the last shooting done for Magnolia Petroleum Company, shows the very close conformity of the seismic work to the subsurface structure.

The discovery of this field can be credited to three main geophysical factors: first, the recognition of an anomalous gravity condition; second, following up this gravity survey with seismic work, and from a very small amount of seismic data recognizing that an anomalous subsurface condition existed; third, the obtaining of enough seismic control at Wilcox depth to be reasonably certain of the faulting and associated dip into the fault. This meant obtaining good quality deep data.

ACKNOWLEDGMENTS

We wish to thank Shell Oil Company, Atlantic Refining Company, and Cities Service Oil Company for providing their geophysical information. We wish to thank Magnolia Petroleum Company for their permission to publish this paper and Mr. George Hager and Mrs. Betty Richardson, together with other members of the Geophysical, Geological and Land Departments, for their assistance in the preparation of the material presented here.

GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 509–516, 7 FIGS.

CASE HISTORY OF WILD GOOSE GAS FIELD, BUTTE COUNTY, CALIFORNIA*

WALLACE L. MATJASIC†

ABSTRACT

The discovery well of the Wild Goose gas field was drilled and completed in 1951 on a structure located by a reflection seismograph survey conducted in 1950. An additional seismograph survey was made subsequent to discovery to define the structure better for further development. The illustrations include two seismic cross sections, a contour map based on the original seismic reflection data, an aeromagnetic map, a structure contour map, and an electric log of the discovery well.

The producing sands are in an interval between the Forbes shale of Upper Cretaceous age and the overlying Capay shale of Eocene age.

INTRODUCTION

The Wild Goose gas field lies on the flat plain of the Sacramento Valley immediately northwest of Marysville Buttes, in Butte County, California, approximately midway between the Sutter Butte and Afton gas fields (Fig. 1). It derives its name from the Wild Goose Country Club on which property the discovery well was drilled. The field was discovered on August 5, 1951 by the completion of the Honolulu-Humble "Wild Goose" No. 1, Section 17, T17N/R1E, after an initial production test of approximately 3,500 MCF per day from the "Kione" sands of Upper Cretaceous age. This well was located after a reconnaissance seismograph survey in 1950 indicated the presence of a small dome-shaped structure.

Interest in the general area was first created in early 1944 by the presence of a residual gravity maximum located about three miles northwest of the present field, and by the possibility that this gravity maximum might represent a structure. Should the structure be present, it was conceivable that gas could be obtained from the sand producing in the Afton gas field which had just been discovered approximately six miles to the north.

SEISMIC SURVEYS

A seismograph survey of the gravity anomaly was begun by Honolulu Oil Corporation March 22, 1944, but was discontinued prior to completion because of other commitments. In 1950 Humble Oil & Refining Company and Honolulu Oil Corporation began a joint seismograph survey of the general area. It was during this joint survey that the seismograph discovered the existence of the Wild Goose structure.

Twenty-four trace 1,100-0-1,100 ft split spreads were used with shot points

* Presented at the Pacific Coast Regional Meeting of the Society at Los Angeles, November 6, 1953. Manuscript received by the Editor March 12, 1954.

† Honolulu Oil Co., Bakersfield, Calif.

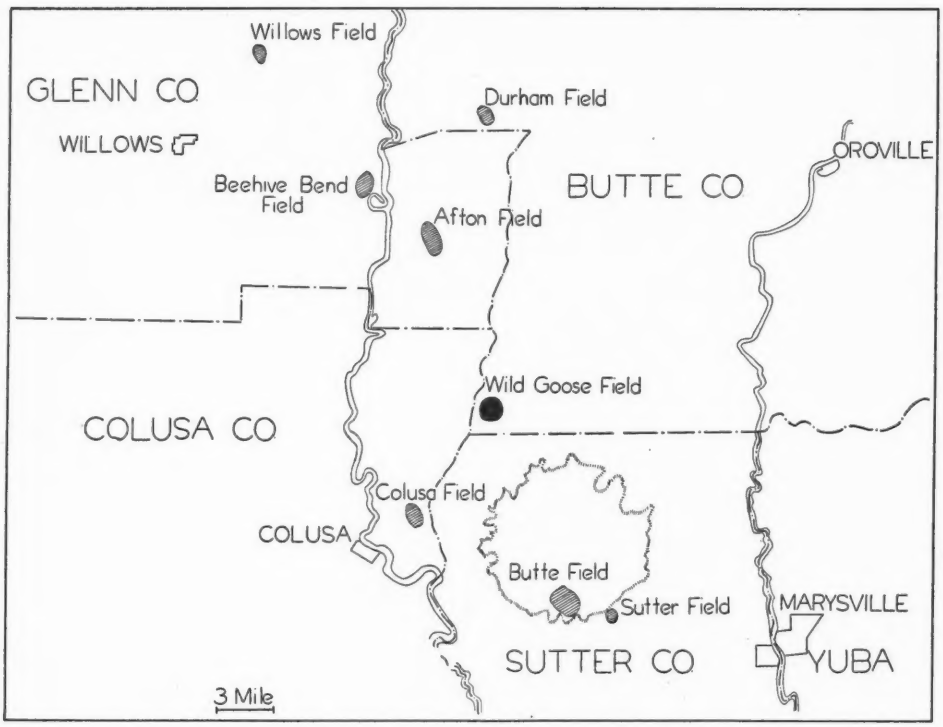

FIG. 1. Location map of the Wild Goose Gas Field.

offset a minimum distance from the center of the spreads. Continuous profiling afforded complete subsurface coverage; however, reflections were of poor quality and few in number. In part this may have been due to the fact that the seismic lines were running in and out of basalt, particularly to the south and west of the structure's crest, making it necessary to maintain continuous correction control to assure that basalt velocity anomalies did not obscure the true structural condition present in the area. In some instances records could be improved by digging out two to twelve inches from the ground surface in order to plant the jugs below a mat of tule roots which acted as an absorption layer. Two seismic lines bisected the structure. The first line to be shot across the structure was an east-west line (Fig. 2) which provided the original evidence that a structure existed. Very few reliable reflections were obtained below a subsea depth of 3,000 feet. However, the seismic cross section revealed sufficient evidence of dip reversal to warrant additional investigation. The reflections plotted as solid lines represent those considered reliable, the long dashed lines represent poor reflections, and the short dashed lines are questionable reflections. The northwest-southeast line (Fig. 3) across the structure best exhibits the consistency of the direction of the reflections, particularly at subsea depths above 4,000 feet. The

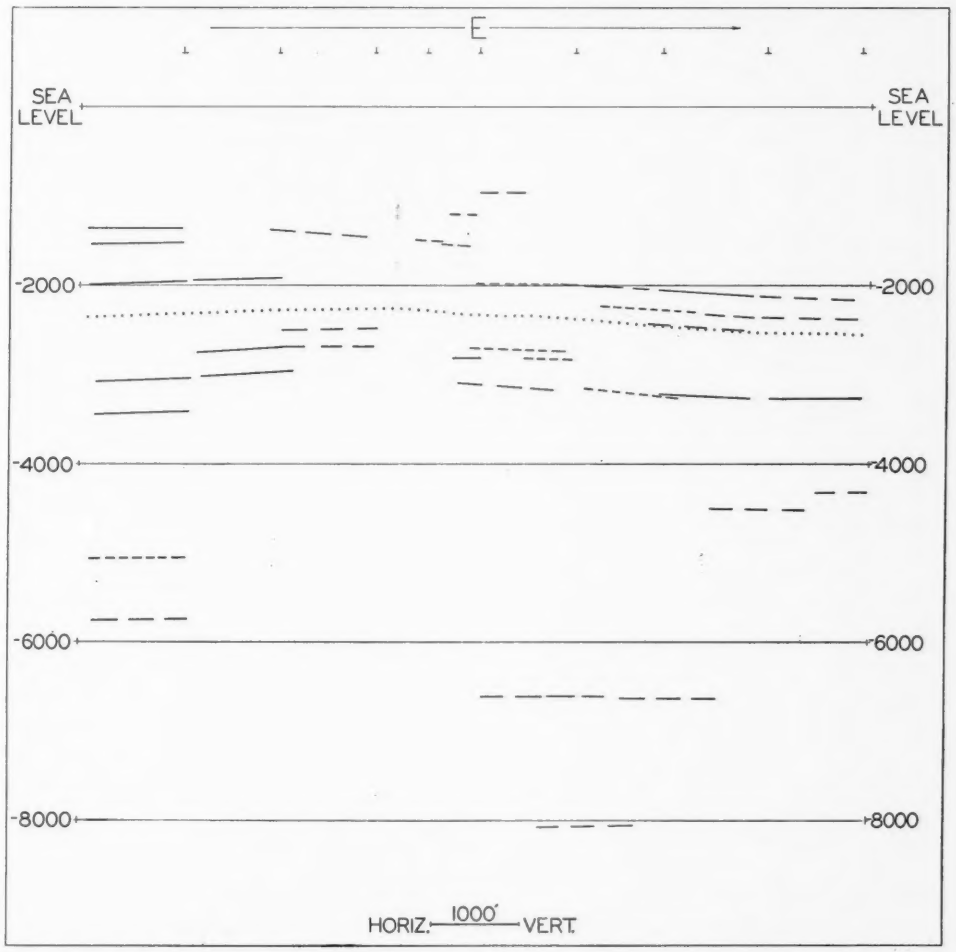

FIG. 2. East-West seismograph cross section through the Wild Goose Gas Field.

dotted line on these illustrations represent the phantom horizon used in constructing the seismic contour map.

Four additional seismic lines were shot around the perimeter of the structure to evaluate it more completely prior to drilling the first well. After the discovery well was drilled additional seismic lines were shot in preparation for the development program.

The first seismic contour map of the structure was prepared by Western Geophysical Co. (Fig. 4). This map demonstrates the type of structure at a contour interval of 50 feet at an arbitrary depth which later proved to be about 135 feet above the Wild Goose sand series. Areas of poorest reflection control are indicated by dashed contour lines rather than continuous lines. No well velocity

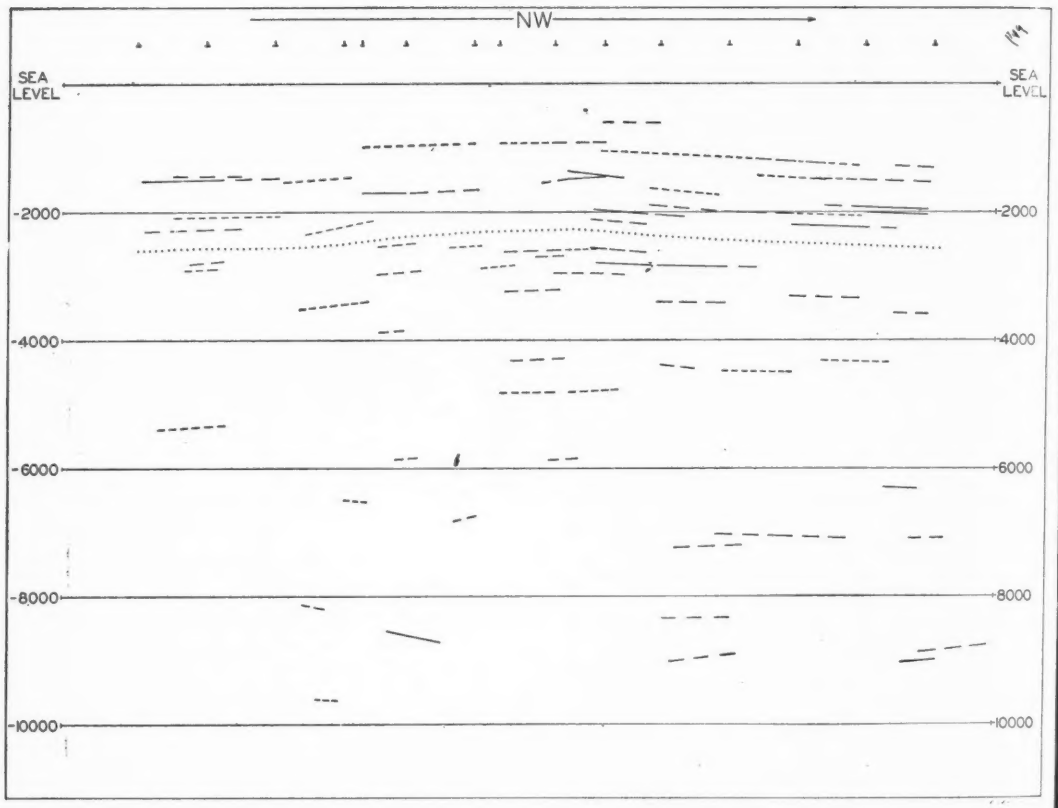

FIG. 3. SE-NW seismograph cross section through the Wild Goose Gas Field.

control was available in the area at the time this map was made. The location of all of the wells drilled on and in the immediate vicinity of the structure are shown on this map. The discovery well was located within the highest closing seismic contour on the structure. All subsequent producing wells, except Wild Goose No. 2 were similarly located.

AEROMAGNETIC SURVEY

An aeromagnetic map of the same area included in the seismic map was prepared by Fairchild Aerial Surveys, Inc. as part of a regional survey some two years after drilling the discovery well (Fig. 5). This map exhibits contours of the observed magnetic values with normal regional gradient removed. The contour interval is 10 gammas. All well locations are indicated. Hard basalt was encountered in two of the wells in the field. Wild Goose No. 2, located about one mile west of the discovery well and adjacent to a magnetic low, drilled through 129 feet of basalt. The more recent drilling of Hangtown No. 2, immediately north of the discovery well and on a magnetic high, unexpectedly encountered hard

FIG. 4. Seismic contour map of the Wild Goose Gas Field. Contour interval is 50 ft.

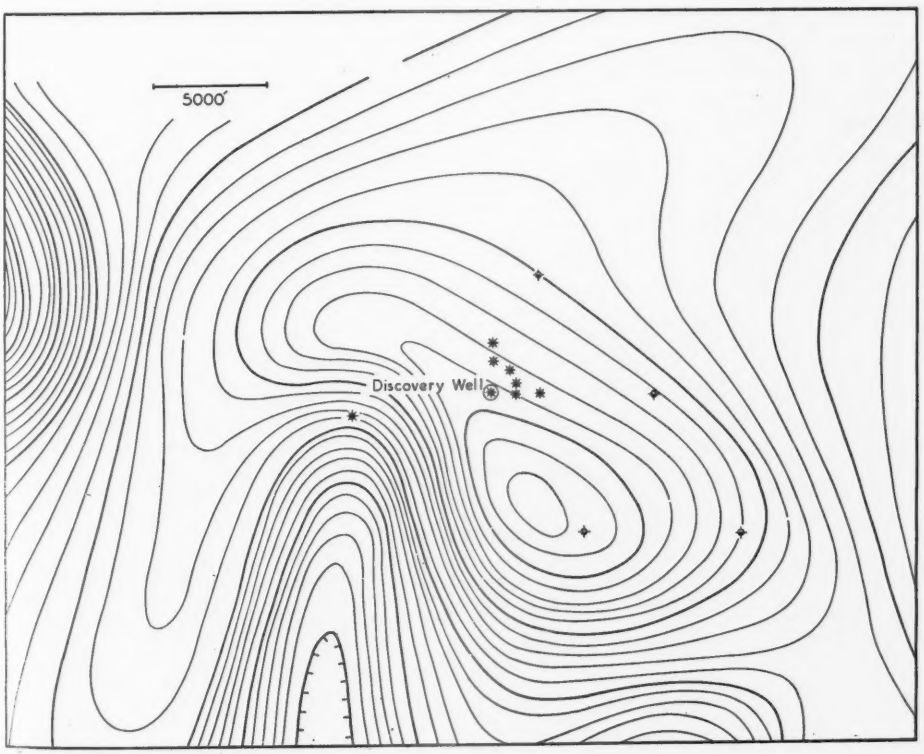

FIG. 5. Aeromagnetic map of the Wild Goose Gas Field. Contour interval is 10 gammas.

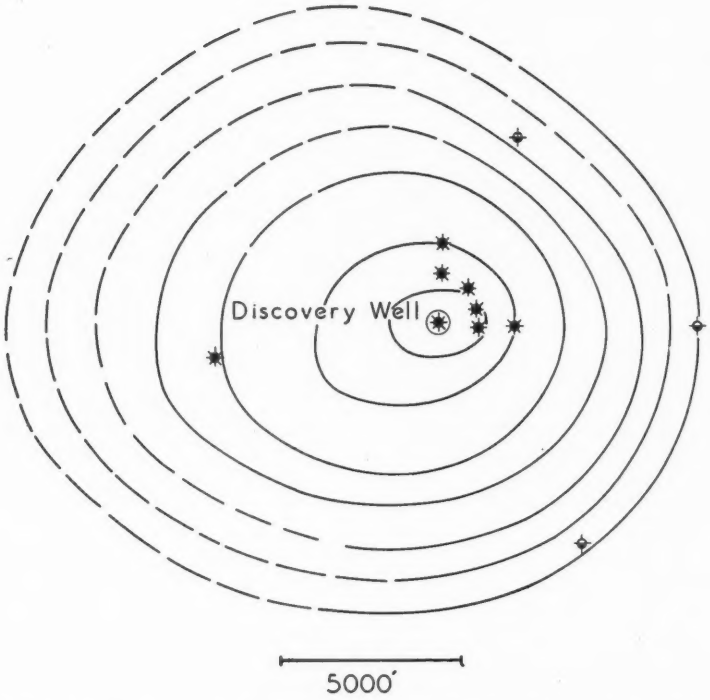

FIG. 6. Structure contour map of the Wild Goose Sand series. Contour interval is 50 ft.

basalt, penetrating some 56 feet. Since none of the other wells surround Hangtown No. 2 encountered basalt, it is assumed that this is an isolated remnant. In general, the top of the basalt layer is 1,200 to 1,400 feet deep.

COMPARISON OF SEISMIC PICTURE WITH WELL DATA

A structure contour map of the field (Fig. 6) based on well control shows reasonable agreement with the original seismic contour map. It is especially noteworthy that the discovery well appears on both maps within the highest closing contour, and that the general position and outline of the structure on the two maps is similar. The principal difference between the two maps is the larger amount of relief shown on the structure map. The structure contours are drawn on the top of the Wild Goose sand series at an interval of 50 feet. Thus the two maps have the same contour interval and vary in depth by only 135 feet at the crest of the structure.

DEVELOPMENT OF FIELD

The wells were completed from several zones within the series of Wild Goose or "Kione" sands (which includes the Afton) lying below the Capay shale of Eocene age and above the Forbes shale of Cretaceous age. These sands are

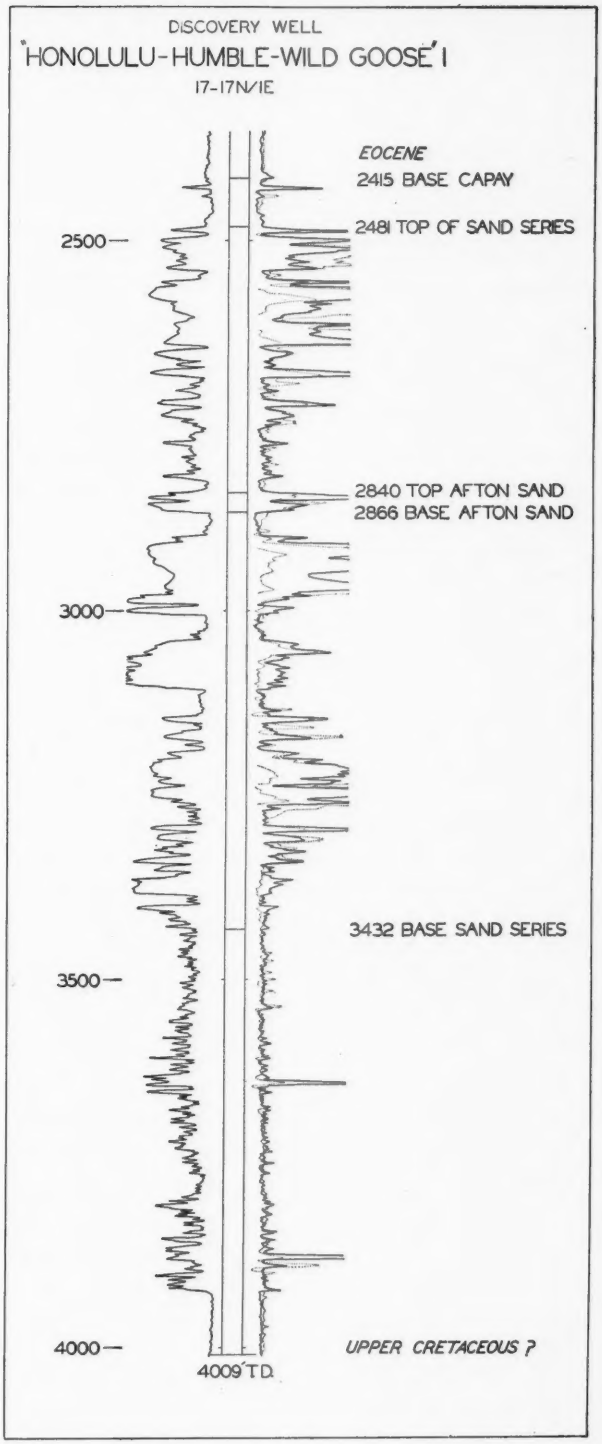

FIG. 7. Electric log of a portion of the discovery well, Honolulu-Humble Wild Goose No. 1.

Paleocene and/or Upper Cretaceous in age. Some geologists consider only the sands below the Afton sand as Kione, Upper Cretaceous, and those above the Afton as Paleocene.

The Wild Goose sand series is approximately 950 feet thick as shown on the electric log of the discovery well (Fig. 7). The net sand thickness is about 640 feet and the net thickness of gas bearing sands is about 400 feet. The productive sands are light to medium gray, quartzose, fine to medium grained, soft to firm, clean to silty, with good permeability and porosity. Carbonized plant remains are common and some of the sands appear to be ashy. Although the sand members in general are continuous throughout the field, some of them grade laterally in whole or in part to siltstone from well to well without much over-all change in total sand thickness. Foraminifera are rare and usually are arenaceous types, so that exact age determination is not practical. The general lithology suggests the productive zone is an estuarine deposit rather than true marine, which also may explain the lack of diagnostic fauna.

There are eight producing gas wells in the field and four dry holes within the immediate area. The average development well was drilled in less than two weeks. To date (October 1, 1953) the field has produced approximately 3,500,000 MCF with an average B.T.U. of 810. It is expected that this field will prove to have a very substantial reserve owing to the exceptionally thick section of productive gas sand, which compares favorably with that of the Rio Vista gas field in thickness.

ACKNOWLEDGMENTS

The author wishes to acknowledge appreciation to Humble Oil & Refining Company and Honolulu Oil Corporation for permission to publish this paper, to J. H. McMasters, C. M. Cross, and Carl Savit for their help and suggestions, and to Hollis Bertrand, who prepared the illustrations.

GEOPHYSICS, VOL. XIX, NO. 3 (JULY, 1954), PP. 517–528, 9 FIGS.

NON-TECHNICAL PAPERS

GEOPHYSICAL ACTIVITY IN 1953*

SIGMUND HAMMER†

GEOPHYSICAL ACTIVITY IN THE OIL INDUSTRY

Geophysical activity in the search for oil in 1953 on a global scale maintained but probably did not exceed the record high established in 1952. Increased activity occurred in Mexico, in South America, and in Africa and the Far East. These increases offset small but definite declines in geophysical activity in the U. S. and in Canada.

The over-all world-wide effort in 1953 utilized the full-time services of 1,100 geophysical crews. This figure is slightly higher than for 1952 but includes other methods which were not reported the previous year. The crews were distributed among the various geophysical methods as follows: seismic 941, gravity 129, magnetic 19, and others 16. Comparative data reported for 1952 were seismic 948, gravity 125. World-wide seismic operations in 1953 were lower than in 1952 by an average of seven crews; gravity operations were up four crews. Comparative data are not available for magnetic and other methods.

In the U. S. and Canada, the total number of seismic crew-months totalled 9,379, down 422 or 4.3%. This represents a loss, substantially, of the full-time services of 35 seismic crews. Gravity totalled 1,048 crew-months, down 27 (2.5%) or about two less crew-years.

The month-by-month fluctuation of seismograph and gravity operations in the U. S. is shown for the ten-year period up to the end of 1953 in Figure 1. The very sharp decline in seismic activity which began in October, 1952, was slowed but continued the downward trend through 1953. The number of seismic crews in the field at the end of the year was 612. Gravity operations in the U. S. continued at a relatively constant rate. The number of gravimeter crews in operation at the end of the year was 80.

The month-by-month fluctuation of field crews in Canada is shown in Figure 2. The similarity to the curves for the U. S. is remarkable. However, it is noteworthy that gravity work in Canada suffered a gradual decrease during 1953, whereas the seismic work, after a sharp drop in the first quarter, fluctuated about a level average during the last three quarters and showed a definite sharp rise at the end of the year.

* Report of the Committee on Geophysical Activity of the Society of Exploration Geophysicists. The members of the committee are A. A. Brant, Herbert Hoover, Jr., Kumiji Iida, A. Garcia Rojas, Raoul Vajk and Sigmund Hammer, Chairman. Previous annual reports of this committee were issued under the authorship of the former chairman during the past six years, Dr. E. A. Eckhardt. His retirement marks a milestone for the Committee.

† Gulf Research & Development Company, Pittsburgh, Pa.

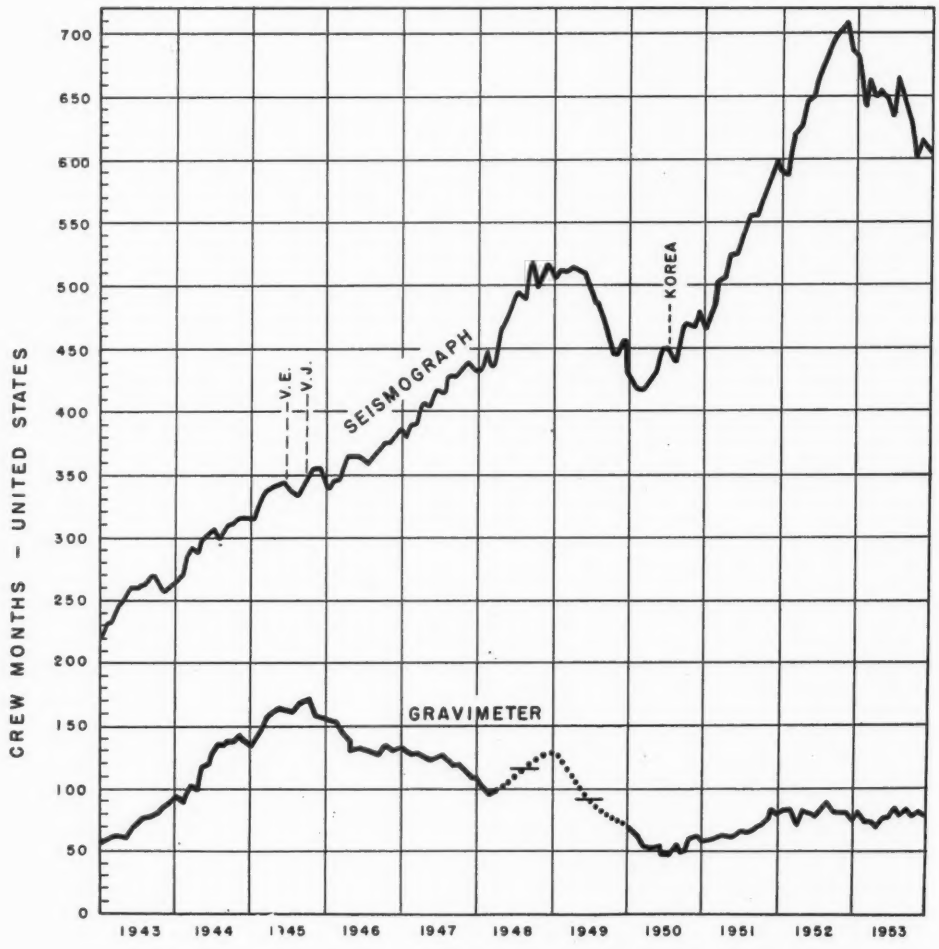

FIG. 1. Monthly variations in seismograph and gravimeter crew-months in the U. S.

The geographic distribution of 1953 U. S. seismic operations is shown in Figure 3. Again, as for the first time last year, Texas and Louisiana together account for slightly less than one-half of the total activity. The concentration of work in the Rocky Mountain area continued through 1953 but a major shift occurred in the Williston Basin from North Dakota into Montana. Seismic work in North Dakota decreased 91 crew-months, a drop of 21%. In Montana the increase was 163 crew-months, up 28%. Other large changes were in Texas—down 211 crew-months or 8%—and in Louisiana—up 185 crew-months or 17%. Substantial decreases were also recorded in California, New Mexico, and Colorado. A definite increase occurred in Wyoming. Other changes and shifts of seismic operations in the U. S. are listed in Table I.

The areal distribution of 1953 gravimeter operations in the U. S. is shown in

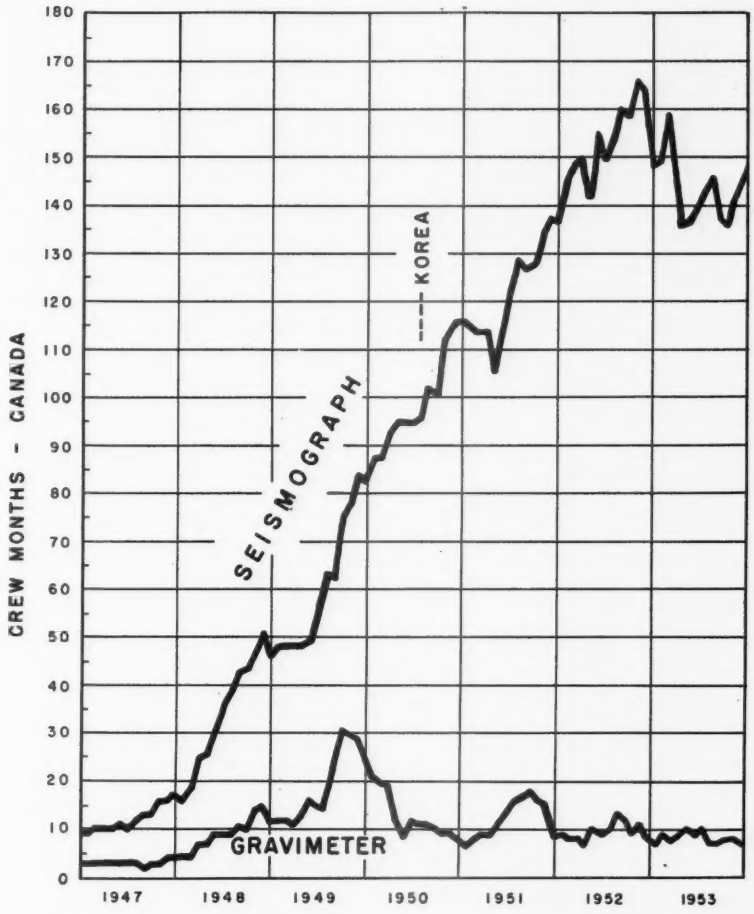

FIG. 2. Monthly variations in seismograph and gravimeter crew-months in Canada.

TABLE I. SEISMOGRAPH CREW-MONTHS IN U. S.

State	1952	1953	Change
Texas	2,670	2,459	− 8%
Louisiana	1,083	1,268	+17%
Mississippi	203	191	− 6%
Oklahoma	411	404	− 2%
New Mexico	657	600	− 9%
Colorado	252	216	−14%
Wyoming	519	543	+ 5%
Montana	574	737	+28%
North Dakota	436	345	−21%
California	283	229	−19%
Other	870	674	−22%
Total	7,948	7,666	−3.7%

Figure 4. More than half, nearly 60%, of all gravity work in the U. S. was shared between Texas and Louisiana. More than half of the remainder was in the Rocky Mountain area. Substantial amounts of gravity work were also done in California and in the Southeastern States. As with seismic work, a major shift of gravity activity was made in the Williston Basin out of North Dakota into Montana. Declines in gravity work occurred in California, Oklahoma, New Mexico, and Mississippi. Substantial increases took place in Colorado, Texas, and Louisiana. Additional information on areal distribution and shifts of gravity operations in the U. S. is given in Table II.

TABLE II. GRAVITY CREW-MONTHS IN U. S.

State	1952	1953	Change
Texas	381	387	+ 2%
Louisiana	153	174	+14%
Mississippi	57	51	−10%
Oklahoma	13	3	−77%
New Mexico	54	47	−13%
Colorado	19	30	+58%
Wyoming	30	30	none
Montana	72	94	+30%
North Dakota	43	3	−93%
California	89	69	−22%
Other	54	61	+13%
Total	965	949	−1.7%

World distribution of seismic explorations for petroleum is shown in Figure 5. Two-thirds of all seismic activity was in the U. S. Canada ranked second with slightly less than one-sixth of the world total. Including substantial operations in Mexico and some in Alaska, the North American continent accounted for 85% of all seismic activity in petroleum exploration during 1953. A considerable amount of seismic work was also reported in the Eastern Hemisphere, about one-tenth of the world total. About half of this work is credited to Europe, with Africa, Italy, the Far East and the Middle East following in that order. About 5% of the world seismic effort during 1953 was in South America, with Venezuela and Argentina the principal participants.

The world distribution of gravimeter operations is shown in Figure 6. The U. S. accounted for 949 crew-months or over 61% of the total. Canada, as a single nation, ranked second with a total of 99 crew-months or 6.4% of the world total. Africa and Mexico followed with 69 and 48 crew-months each, respectively. North America, taken as a whole, did 1,096 crew-months of gravity work or 70.75% of the world total. In South America, the total was 144 crew-months, 9.3% of the total. A substantial amount of gravity work was reported in the Eastern Hemisphere—a total of 309 crew-months or one-fifth of the world total.

Magnetic exploration is apparently staging a comeback. This is, of course, largely due to the many advantages of the airborne magnetometer. However, a relatively great amount of ground magnetic work was also reported. In the U. S.

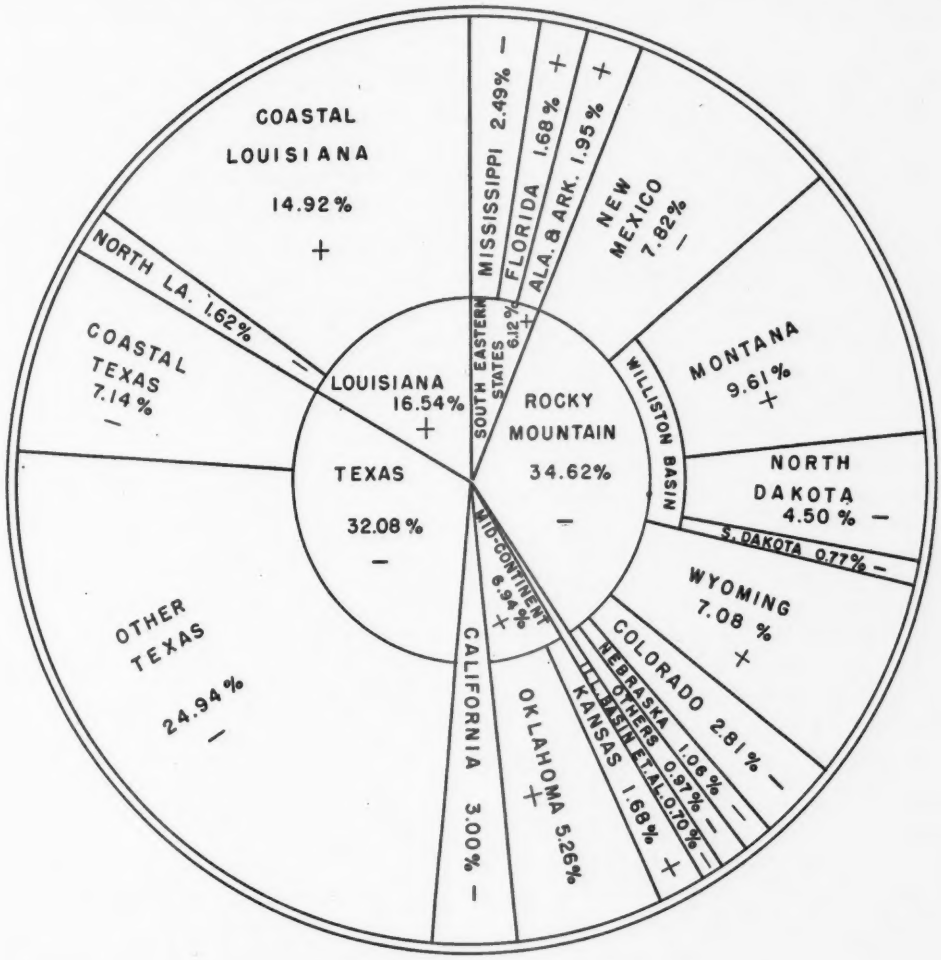

FIG. 3. Distribution of 1953 seismograph operations in the U. S.

and Canada, a total of 70 crew-months of magnetic work were reported. Of these, it can be estimated that about 30 crew-months were airborne, with an output of about 200,000 miles of continuous aeromagnetic profile. South America reported 83 magnetometer crew-months and the Eastern Hemisphere 73, for a world total of 226 magnetometer crew-months. A natural consequence of the high output of the airborne magnetometer was the growth of specialized magnetic interpretation consultants. Incomplete returns report that magnetic interpretations, pertaining to petroleum exploration, were performed during the year on 79,000 square miles of aeromagnetic data. It is probable that a large backlog of magnetic interpretation remains to be done.

Explorations on the continental shelves and other offshore areas continued active. Totals of 102 water-borne seismic crew-months, 27 underwater gravimeter

crew-months, and 3 offshore aeromagnetic crew-months were reported. About three quarters of this activity was in the Gulf of Mexico, offshore Texas, Louisiana, and Florida. The remainder was off California and Trinidad and in the Persian Gulf. In anticipation of forthcoming expanded offshore explorations, it may be pertinent to remark that the only practicable methods of evaluation ahead of the drilling platform and drill are provided by geophysics.

The investment by the oil industry of the world in geophysical exploration during 1953 probable was on about the same level as in 1952, namely $350,000,000 to $400,000,000. The slight decline in seismic activity, which accounts for about 90% of the total cost, was probably offset by small increases in unit costs.

The decline in the use of geophysical tools by the petroleum industry in the search for new oil fields in the U. S. and Canada during the past year is a matter

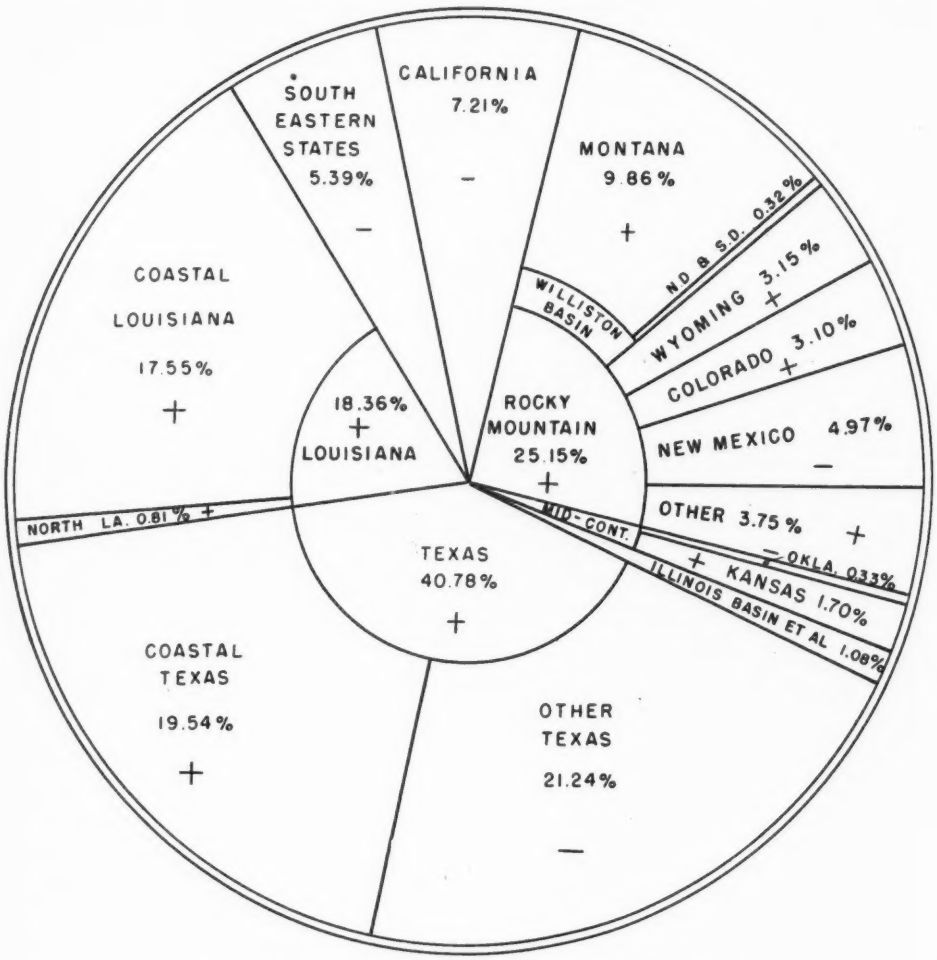

FIG. 4. Distribution of 1953 gravimeter operations in the U. S.

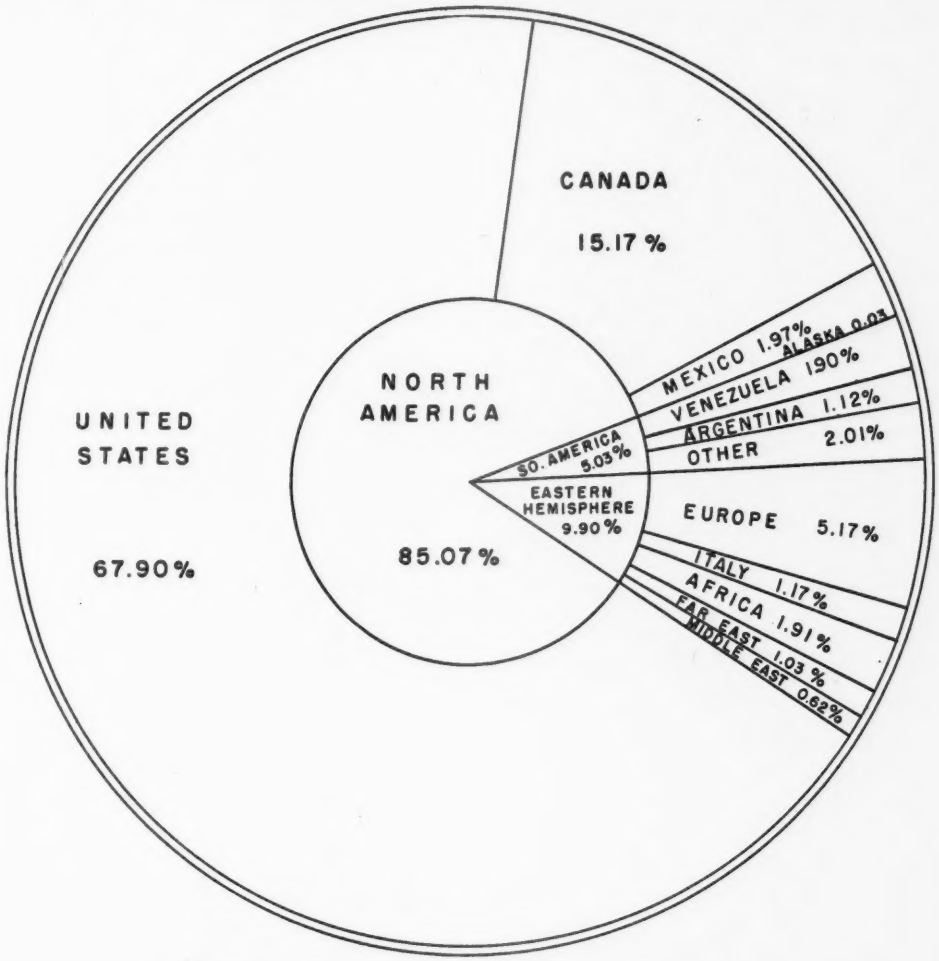

FIG. 5. World distribution of seismograph operations in 1953.

of serious concern. The effectiveness of the geophysical methods has been proved beyond doubt by the results of wildcat drilling. Recasting Lahee's data for 1952 (Lahee, 1953) into a slightly different form, we find that the chance for discovering a new oil field by wildcat drilling depends upon the basis for choosing the site according to the following table:

TABLE III. DISCOVERY EFFECTIVENESS OF NEW-FIELD WILDCATS
U. S. AVERAGE 1949–1953*

Basis for Location	Success Ratio
Non-Technical	1 in 27
Technical	1 in 6

* Data for 1953 were kindly furnished by Dr. Lahee in a personal communication.

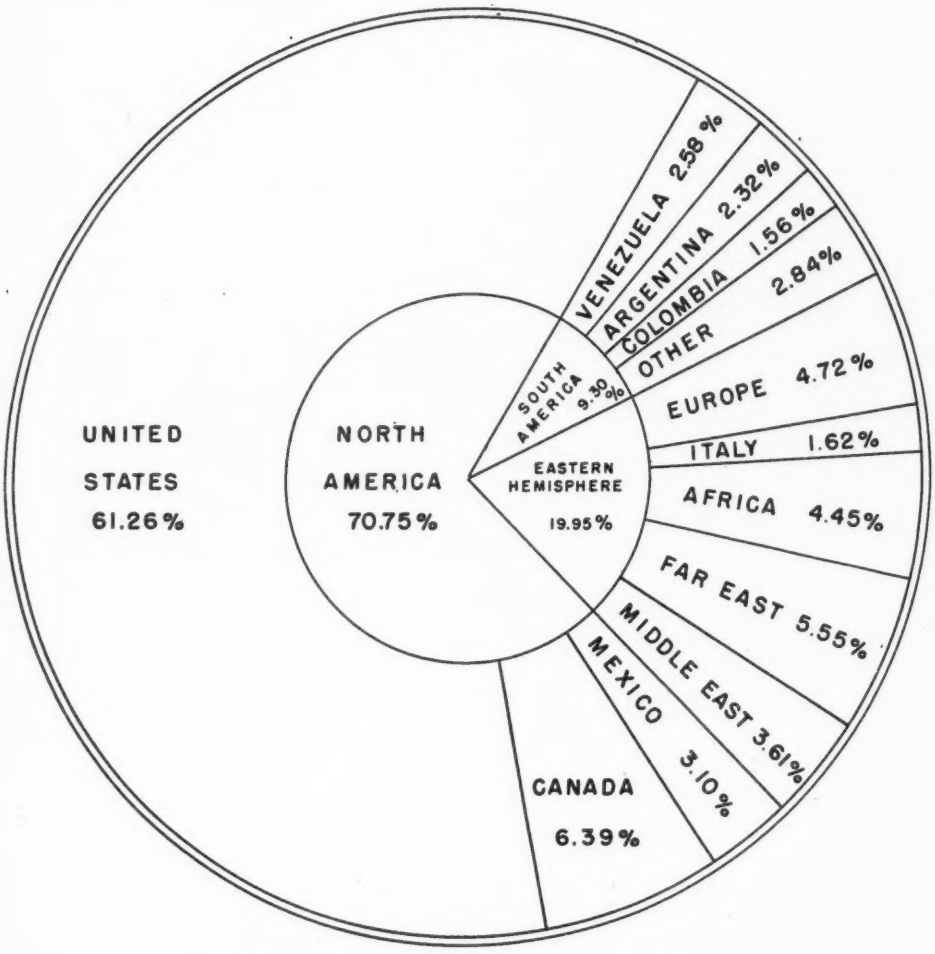

FIG. 6. World distribution of gravimeter operations in 1953.

These data show that the use of geophysics improves the chance for success of a new-field wildcat compared to random drilling by a factor of 450%. The cost of this major improvement, while it represents a very large number of dollars, is a relatively minor factor among the other over-all huge exploration costs. A breakdown of these cost factors by H. J. Struth (1953) is illustrated in Figure 7. The segment allocated to geology and geophysics taken together (Struth's data do not report them separately) is actually less than 10% of the total exploration cost. Leasing and drilling, both of which are vitally dependent upon geology and geophysics for high effectiveness, account for 84% of exploration costs. The petroleum industry is sharply aware of steeply rising oil-discovery costs. These considerations show that what is needed is not less but more and better geophysics. Curtailment of competent geophysical effort, of proven effectiveness,

cannot be recommended or condoned as a sound, long-range business policy to attain effective exploration and low oil-finding costs.

Indiscriminate leasing and drilling, without the best geological and geophysical guidance that can be brought to bear, can only be expected to diminish the effectiveness of exploration and raise discovery costs. It is to be hoped that the downward trend in geophysical activity will be reversed promptly and decisively.

One oil company, which had the rare foresight not to curtail its geophysical exploration during the 1930 depression, gained an important advantage for many years while its competitors struggled to catch up.

Reported plans call for the drilling of over 11,000 wildcats in the U. S. in 1954. As members of the exploration team and as geophysicists, it is our professional responsibility to make ourselves heard by top management so that the vast expenditures for these wildcats will be spent most effectively. Reduction in exploration costs is possible also by advancing the time-table of geophysical evaluation of leases to shorten the period of annual rental payments on untested lease prospects. Let me say again, it is to be hoped that the present downward trend in geophysical activity in U.S.A. and Canada will be reversed promptly and decisively.

GEOPHYSICAL ACTIVITY IN THE MINING INDUSTRY

Mining geophysics—the applications of geophysical methods in explorations for solid minerals—was maintained at nearly the same over-all level both in

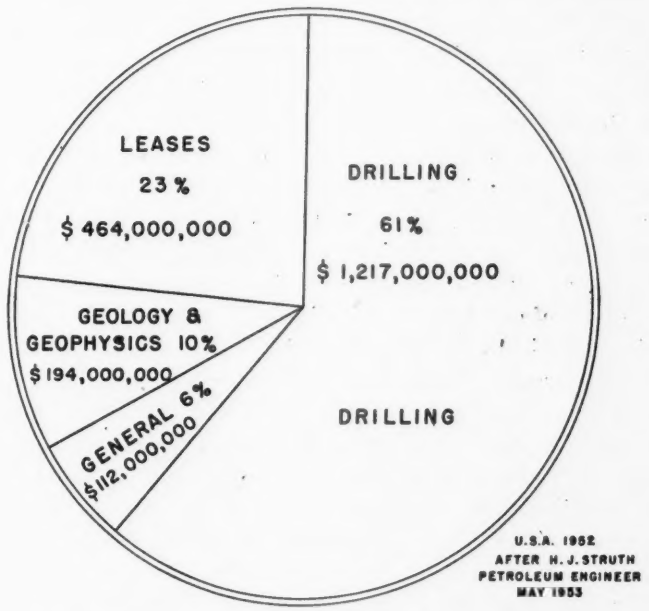

FIG. 7. Expenditure for geology and geophysics is a small fraction of high petroleum exploration costs.

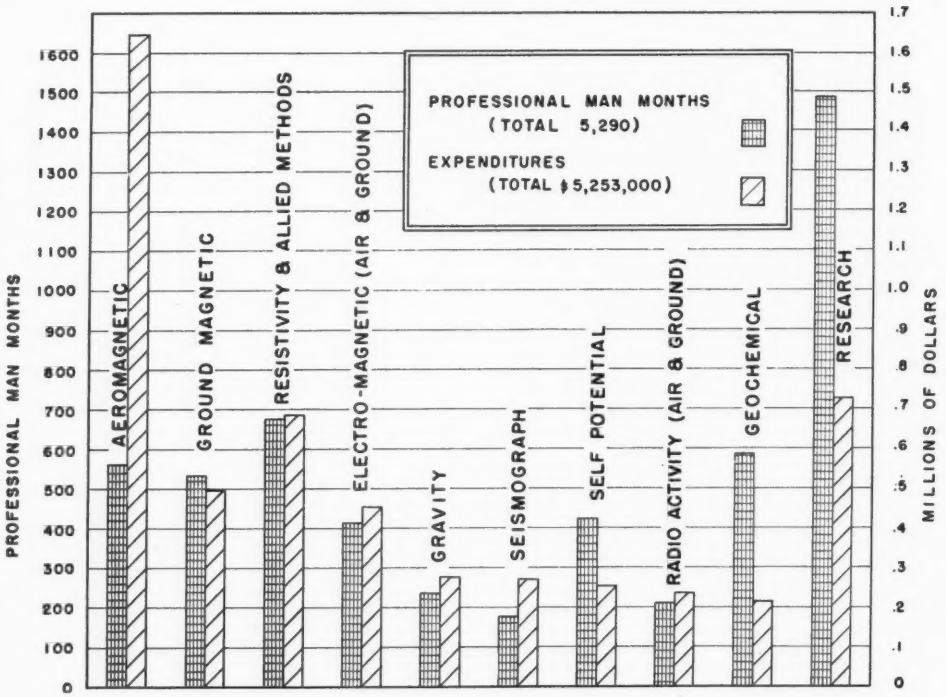

FIG. 8. Mining geophysics—world wide effort in 1953 by methods.

amount of capital invested and in utilization of professional man power. However, it is apparent that the reports are incomplete and that the achieved measure of total effort in the industry is subject to some uncertainty.

The reported data are summarized in the accompanying Figures 8 and 9. Two measures are shown: (a) utilized professional man-months and (b) expenditure converted into U. S. dollars. The reported expenditure in 1953 of more than $5,000,000 sets a record in the applications of mining geophysics. The utilization of a total of 5,290 professional man-months is also a new high.

The distribution of geophysical effort in mining among the different methods during 1953 is shown in Figure 8. The applications of the magnetic method and especially of the aeromagnetic method lead all others. Resistivity and allied electrical methods were second. The rank of the remaining methods depends upon the measure used. On the basis of applied man power, the decreasing order was (3) geochemistry, (4) self-potential, (5) electromagnetic, (6) gravity, (7) radioactivity, and (8) seismic. On the basis of expenditure, the decreasing order was (3) electromagnetic, (4) gravity, (5) seismic, (6) self-potential, (7) radioactivity, and (8) geochemistry.

The distribution of geophysical exploration effort during 1953 in the various countries of the work is shown in Figure 9. Canada has a slight lead over the

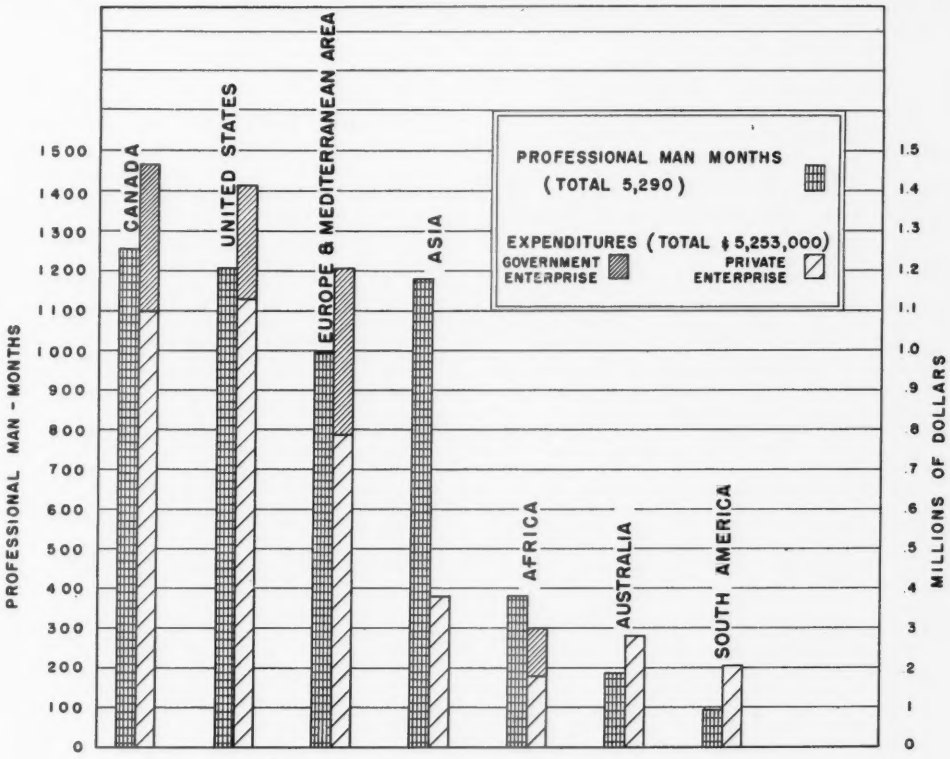

FIG. 9. Mining geophysics—world wide effort in 1953 by areas.

U. S. for first place. Europe, Asia, Africa, Australia, and South America follow in that order.

Comparison of the statistics for 1953 with those for 1952 is subject to some uncertainty due to suspected incompleteness of reports. Accepting the available data at face value, it appears that minor increases in applications were recorded in the electrical and gravity methods and that the use of the various techniques of geochemistry increased substantially during 1953. Slight decreases in use were recorded by magnetics (both ground and airborne) and by seismic and radioactivity methods. Encouragingly for the long-range prospects of the future, research and development reported a substantial increase of about 30% in 1953 compared to 1952.

Exploration for uranium is attracting much interest.[1] A recent development is the use of Geiger counters and scintillometers to check seismic shot holes and slush pits for interesting radioactive indications. Several sources report a total of

[1] For further information contact Joint Advisory Committee of A.A.P.G., S.E.G., S.E.P.M. on Radioactive Mineral Exploration, Dr. F. H. Lahee, Chairman, Box 2880, Dallas, Texas.

506 seismic shot holes, covering a drilled section of 65,000 feet, tested by this method.

Evaluating the utility of geophysics in mining exploration is still at an early stage. Considerable reluctance to publish or even to announce findings based on geophysics continued to be apparent. However, it is encouraging that technical papers and especially case histories of mining geophysics are becoming increasingly available for publication. We are especially pleased that two entire sessions of the SEG program at this meeting are being devoted to technical mining-geophysics papers including case histories of important geophysical discoveries. This is most encouraging. The free exchange of technical experiences, involving the accumulated investments of some tens of millions of dollars, can hardly fail to expedite higher professional achievements and speed the benefits to the industry as a whole.

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SAFETY IS OUR RESPONSIBILITY*

BART W. SORGE†

ABSTRACT

The geophysical industry's safety record compares unfavorably with industry in general and the petroleum industry in particular. These safety problems represent a real challenge, as ways and means must be found to improve safety and accident prevention. We must accept this challenge in order to avoid possible future rules and regulations that may seriously interfere with the efficient conduct of exploration activities. It is just plain good business to insist on safe operations of geophysical field parties.

INTRODUCTION

Geophysicists are responsible for safety and accident prevention in the geophysical industry because they are or represent management in the majority of geophysical organizations. It is a well established fact that concern about safety and accident prevention in industry is the duty and responsibility of management. This is due to the fact that management alone has control over the design and construction of equipment, working conditions, and work procedures used. According to a somewhat simplified definition, anyone concerned about getting someone else to do work exercises a management function and, as a result, shares management's responsibilities. Since the activities of most geophysicists include directing others to do work, we are part of management. Therefore, safety and accident prevention is *our* responsibility. We must take an interest in safety matters and must do everything possible to improve equipment, working conditions, and work procedures. We must make employment in geophysical exploration safer and more attractive so that we may be assured the ample supply of new recruits to our ranks which is so necessary to guarantee the continued growth of the geophysical exploration industry.

THE SAFETY PROBLEM

What is this problem of safety and accident prevention? Fundamentally, safety is the prevention of the results of chance by intelligent foresight. Safety engineering is an effort to reduce accidents to an absolute minimum and eliminate the resulting injuries as much as possible. Safety is definitely an operating problem, the responsibility of those who control equipment, work procedures, and working conditions. Safety is also a useful tool to improve operating efficiency and profits. In most cases, a safely operated geophysical crew is also an efficiently operated one. A survey recently made showed that a group of safely operated geophysical crews accomplished more work than a group of parties with a poor

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safety record and at the same time showed a net profit twice as great, after all operating expenses. In other words, safety is just good business. It is serious business and warrants the undivided attention of management in the geophysical industry. Effective safety measures are worthwhile, not only to decrease the direct cost of doing business, such as the reduction in insurance premiums for compensation and liability insurance, but also, indirectly, to reduce the cost of many other operations inherent in the business of carrying on geophysical surveys. The real costs of accidents are at least three to four times greater than the direct costs, which are more readily determinable.

There are, of course, some who feel that an effort to reduce accidents is not necessary since insurance companies pay the costs of compensation and medical payments. Unfortunately, however, insurance companies are not in the business for pleasure. They are in business to make money. A high rate of accidents and injuries will result in higher insurance costs. Most insurance carriers consider the safety performance of an insured satisfactory only as long as they do not have to pay out in compensation and medical payments more than sixty percent of the total amount of the premium received. Whenever this percentage is exceeded, either the insurance premiums are raised or the contract is cancelled.

PUBLIC RELATIONS AND SAFETY

Much concern within the geophysical industry has been shown recently about the problem of good public relations. Much money, time, and effort are being expended by business organizations and also some associations to improve public relations as they pertain to geophysical exploration. Safety and accident-free operations can be a great aid towards better public relations. Basically, good public relations are nothing but the serious effort of making friends for our endeavor. Good public relations are aided by doing something well and letting others know about it in order to receive credit for it. Safety and accident prevention present the geophysical industry a useful tool towards improved public relations. This aid has been present a long time but until recently was not recognized. The absence of accidents definitely creates good will and has a tendency to attract badly-needed qualified people into our ranks. Unfortunately, the accident that has been prevented is not news but the accident that happened is always news—bad news—bad for good public relations. For this reason, the creation of a good safety record can be the means of creating good public relations. This problem of good public relations is one affecting all parts of the geophysical industry. It, of necessity, must be a cooperative effort with *all* operators participating because, unfortunately, a few not seriously concerned about safety can undo the effort put forth by the large majority.

EMPLOYEE RELATIONS AND SAFETY

Another problem which has recently received more attention is that of good employee relations. Successful employee relations are necessary in any well

functioning business organization. They build confidence between management and the rest of the team and promote efficiency. Safety is a tool towards better employee relations which no serious business organization can afford to neglect. Safety efforts, properly presented, tend to promote good will among workers. Safety efforts present an opportunity for management to show a real interest in the personal welfare of the employee. To further good employee relations, a safety program should stress the objectives of reducing needless suffering and hardship on the part of the employees, in addition to saving the company money by increasing profits in the form of reduced insurance and accident expenditures.

Other industries have found that it pays to make use of safety and accident prevention efforts to improve both public and employee relations. There is no reason why the geophysical industry cannot do the same. Once management realizes its responsibility for safety and accident prevention, the first and most important step has been taken.

SEG SAFETY COMMITTEE

To aid the cause of safety and accident prevention, the Council of the Society in 1951 agreed that the president appoint a Special Committee on Safety. As a result of service rendered and the need that exists for such a committee, the safety committee was made a standing committee of the Society at the annual meeting in Houston in 1953. The committee was charged with the duty of doing everything possible to further the cause of safety and accident prevention. The committee's first task was to determine the status of safety and accident prevention pertaining to geophysical operations and make comparisons with that of other industrial activities. Very little information was available due to the fact that only a few geophysical organizations reported their safety statistics to the recognized safety agencies, such as the American Petroleum Institute, The National Safety Council, and the Bureau of Mines. For this reason, it was necessary to encourage geophysical operators to submit statistics on the basis of which the status of safety and accident prevention could be judged. As a result of the committee's efforts, sixty organizations submitted their information to the American Petroleum Institute in 1951. Among the geophysical contractors, the number reporting increased over one thousand percent, since in prior years only three organizations bothered to make their safety information available. Most oil companies operating their own geophysical crews have always submitted safety information through their safety engineering departments. The information that then became available as a result of the safety committee's efforts was rather startling, as is shown in Table 1.

The yardsticks used to measure safety performance have been universally adopted by all safety agencies and are applied to all industrial groups in the United States. The frequency of lost time personal injuries is measured on the basis of the number of such injuries per million man hours worked. The severity (that is, the seriousness) of such lost time personal injuries is measured by the

TABLE I

DISTRIBUTION OF ACCIDENTS IN THE PETROLEUM INDUSTRY COMPARED WITH ALL INDUSTRY, 1951

	Frequency	Severity
All Industry	9.06	.97
Petroleum Industry	10.50	1.29
Exploration Group	23.33	1.486
Contact Geophysical	53.50	2.106

number of work days lost per one thousand man hours worked. From Table 1 it can be seen that the lost-time personal-injury frequency of the petroleum industry in 1951 was only slightly higher than that of all industries in the United States. The exploration part of the oil industry, however, reported a much worse performance from a safety point of view. As a result, it became desirable to analyze this information further in order to find possible clues which might aid the committee in planning its action to further the cause of safety and accident prevention. The frequency of 53.5 and the severity of 2.106 shown in Table 1, represented the safety performance of thirty-five contract organizations. When evaluating these statistics, it must be kept in mind that this group represented only one-third of the total contract companies in the business—the third that appeared to be sufficiently interested in the problems of safety and accident prevention to keep statistics and make them available. It is not unreasonable to assume that the safety performance of the remaining organizations was at least as bad or worse. However, even on the basis of the statistics reported, a serious problem existed. The improvement of those unsafe conditions and practices presented a real challenge which had to be met in order to continue to attract desirable workers to our ranks. Safety performance also needed to be improved to avoid possible future regulation on the part of government agencies. The geophysical industry could not afford to continue its lack of interest in matters pertaining to safety and accident prevention.

Safety Statistics

A questionnaire sent out by the Safety Committee to the geophysical industry resulted in answers to various safety questions from sixty-three percent of the organizations. Seventy-three percent of those returning questionnaires favored the keeping of geophysical safety statistics either by the Safety Committee or the Tulsa office. As a result, beginning in 1953 the Safety Committee, through the Tulsa business office of the SEG, has gathered safety statistics from all geophysical operators. This information has been made available at least quarterly in the publication "Exploration Safety Tips," published by the Standing Committee on Safety. This is the only way in which useful statistics can be obtained in time to be of real value. It is also the only way in which safety statistics for geophysical operations only can be gathered, since the safety agencies that were contacted before beginning this task stated that they were not willing to separate geophysi-

cal exploration from general exploration statistics. An additional advantage is gained in that the geophysical industry now has information available within two to three months instead of the former twelve to fifteen months.

Safety Publications

Beginning in 1953 the Standing Committee on Safety has published two safety booklets valuable in promoting safety and accident prevention on geophysical field parties. "Doodlebuggin' the Safe Way" is published quarterly and is written in a humorous style but at the same time contains a wealth of safety suggestions useful to all field party personnel. "Exploration Safety Tips" is a booklet published bi-monthly, designed to be of interest to those employees on geophysical field parties who are concerned with the planning of safety and accident prevention. It is in this booklet that current information on geophysical safety statistics is published, as well as summaries of the latest data available through The Geophysical Accident Information Exchange. Both of these pamphlets have been well received, as borne out by their wide circulation since they became available.

Safety Posters

Due to unusual working conditions encountered in geophysical field operations, many of the safety posters available through recognized safety agencies do not apply to the safety problems they encounter. As a result, the Safety Committee has gathered and made available through the business office of the society, on a non-profit basis, a large variety of safety posters dealing with the particular problems of safety affecting geophysical operations. Nearly one hundred different posters are now available and are being used by many geophysical organizations. The continuing demand for these posters bears out their value in calling safety measures and precautions to the attention of field party personnel. Over twenty thousand posters have been distributed so far, and it is planned to enlarge the scope of this activity in the future.

Safety Meetings

The Safety Committee has arranged for safety meetings in connection with many regional and all national meetings during the last several years. Speakers on various safety subjects have been provided. The continuing increase in attendance at these safety sessions bears out the fact that there is a real need for the dissemination of safety information among those in the geophysical industry who are responsible for safety and accident prevention. It is the Committee's plan to continue this endeavor and expand it as needed.

The Geophysical Accident Information Exchange

The Geophysical Accident Information Exchange was started in 1951 by members of the Safety Committee on an individual basis. It is now sponsored by

the Committee on Safety of the Society, and presents a worth-while tool by which any organization can aid in furthering the safety efforts of the industry as a whole. Information is submitted monthly on an anonymous basis and is distributed to all participants after all identifying items have been removed. The data are duplicated by a business service organization that has no connection with either the oil or geophysical industry. The number of participants in this endeavor has grown from the original five to forty-three organizations, operating more than half of all seismic crews. Information made available through this exchange makes it possible to recognize often-occurring accident-producing conditions.

The majority of geophysical accidents are very similar in type and can be classified readily. Mr. H. M. Thralls of Seismograph Service Corporation of Tulsa, Oklahoma made a tabulation of the information submitted to the accident exchange during seven months of 1951, and I recently completed an analysis for the years 1952 and 1953. The tabulation of the personal injury accidents during these periods is shown by Table II. An inspection of this information reveals a striking uniformity between the percentage of accidents of each type that occurred in each year. The larger total number of accidents in 1952 and 1953 is due to the fact that the exchange was growing rapidly towards the end of 1952.

Hand injuries, strains and sprains, and eye injuries make up about one-half of the total injuries. Since it is of interest to know whether drillers, recorders, surveyors, shooters, or others had the various types of injuries, an analysis for 1953, shown in Table III, was prepared. This tabulation shows the number of lost days that resulted from injuries of the major types listed which were in-

TABLE II

RELATIVE FREQUENCY OF DIFFERENT TYPES OF INJURIES AND ACCIDENT SOURCES IN THE GEOPHYSICAL INDUSTRY.

	1951*	1952	1953
Total Injuries	497—100%	1086—100%	1139—100%
Lost time Injuries	153— 31%	371— 34%	325— 35%
Hand Injuries	21%	25%	27%
Strains & Sprains	14%	17%	15%
Eye Injuries	9%	10%	12%
Collision or Upset	8%	2%	1%
Falls	7%	5%	6%
Moving Vehicles	6%	7%	7%
Sharp Instruments	5%	1%	4%
Falling Objects	5%	7%	6%
Dermatitis	5%	4%	4%
Cable & Power Reels	4%	½%	1%
Infections	3%	2%	1%
Dynamite & Caps	⅓%	½%	⅔%
Burns		2%	1⅔%
Miscellaneous	13%	17%	14%

* 7 Months.

TABLE III

COMPARISON OF NUMBER OF DAYS LOST BECAUSE OF DIFFERENT TYPES OF ACCIDENTS.

Type of Injury	Drillers	Recorders	Surveyors	Shooters	Others	Total
Strains & Sprains	231	69	88	159	138	685
Hand Injuries	286	43	45	14	50	438
Collison or Upset	31	1	0	6	5	43
Moving Vehicles	459	181	1	6,000	6,246	12,886
Falling Objects	178	3	34	37	25	267
Dynamite & Caps	0	0	0	6	0	6
Others	308	96	216	6,057	136	6,813
Total	1,493	393	384	12,269	6,599	21,138

curred by the various job classifications. Disregarding the three fatalities which occurred in the case of two shooters and an unspecified employee, strains and sprains caused the greatest loss of time. Of the total, about one-third of the injuries of this type happened to drillers and their helpers. In the case of hand injuries, over one-half of the total time lost was incurred by drillers and their helpers. It is evident from this information that the problems of strains and sprains and hand injuries pertaining to drilling operations need a lot of attention. Table IV shows the division of the total number of injuries among the various job classifications. Drillers and their helpers incurred more injuries than any of the others.

To yield further useful information to guide the planning of accident prevention, additional analyses were made of hand injuries and strains and sprains. The results pertaining to hand injuries are shown in Table V. This tabulation shows that moving machinery (in most accidents, drilling machinery), handling of drill pipe, and the breaking of tool joints are responsible for the largest number of hand injuries that have occurred during the period.

A further analysis of types of strains and sprains is shown in Table VI. This tabulation reveals the fact that most strains and sprains have occurred in lifting

TABLE IV

DISTRIBUTION OF ACCIDENTS AMONG DIFFERENT CATEGORIES OF PERSONNEL IN THE GEOPHYSICAL INDUSTRY.

Type of Job Accidents	1951*	1952	1953
Drillers	37%	43%	39%
Recorders	15%	14%	19%
Surveyors	12%	13%	16%
Shooters	10%	10%	8%
Others	26%	20%	18%
Total Accidents	497	1,086	1,139

* 7 Months.

TABLE V

ANALYSIS OF STATISTICS ON HAND INJURIES IN THE GEOPHYSICAL INDUSTRY, 1953.

Type of Hand Injuries	Total	Lost Time	Days Lost
Moving Machinery	47	13	121
Breaking Tool Joints	51	10	92
Handling Drill Pipe	32	7	48
Sharp Instruments	61	11	45
Moving Vehicles	11	4	32
Others	106	19	100
Total	308	64	438

heavy materials. The lifting of drill pipe, casing, and heavy mud sacks caused by far the largest number of these injuries.

From the information available, it is indicated that any safety effort concentrating on the operations of drillers and their helpers will be most likely to yield results in improving any operator's safety performance.

It is also interesting to note from Table III the relatively large number of days lost by recording personnel due to collision or upset of moving vehicles. This is rather unusual, as it is normally considered that surveyors travel far greater distances and over rougher terrain and, as such, are more exposed to injuries involving moving vehicles. An analysis of the various accidents that occurred to recording personnel showed that the majority of them are due to plain carelessness on the part of the injured or the driver of the vehicle and could have been avoided.

The vehicular accidents which were reported to the exchange in 1952 and 1953 are shown in Tables VII and VIII. Table VII shows the vehicles involved in accidents. In both years cars and pickups were involved in the largest number of accidents. This is due to the fact that many geophysical crews work long distances away from their base of operation. Therefore, vehicles needed for crew transportation accumulate high mileage with a resulting high exposure to acci-

TABLE VI

ACCIDENTS CAUSED BY STRAINS RESULTING FROM DIFFERENT OPERATIONS IN THE GEOPHYSICAL INDUSTRY, 1953.

Type of Strains	Total	Lost Time	Days Lost
Lifting	71	33	338
Awkward Position	47	20	144
Pulling or Pushing	23	14	139
Others	24	11	64
Total	165	78	685

TABLE VII

VEHICLE ACCIDENT STATISTICS BY TYPE OF VEHICLE, 1952 AND 1953.

	1952		1953	
	Number of Accidents	Percent of Total	Number of Accidents	Percent of Total
Not Specified	57	23%	31	14%
Cars	53	22%	71	33%
Pickups	54	22%	36	17%
Water Trucks	32	13%	25	12%
Drills	22	9%	20	9%
Recording Trucks	15	6%	14	7%
Shooting Trucks	13	5%	18	8%
Total	246	100%	215	100%

dents. Table VIII shows the type of accidents reported. High speed and improper or dangerous passing are responsible for about forty percent of all accidents. An analysis shows that the high rate of involvement of pickups and cars, coupled with high speed and improper passing, is an indication that much of the driving from town to the prospect and return is done in too much of a hurry. A geophysical organization, intent upon improving its safety record, will find it worthwhile to pay attention to this problem. It is not surprising that excessive speed was responsible for the largest number of vehicular accidents. When making the above analysis, excessive speed was considered responsible whenever the vehicles involved traveled above a safe speed considering road conditions. Many accidents occurred at speeds between 20 and 30 miles an hour. However, these speeds proved too high considering the icy roads encountered in northern areas during the winter. There was a noticeable increase in vehicular accidents due to passing in 1952 and 1953. There is no explanation for this change except that it is in line with a general increase of traffic accidents on a nation-wide basis.

TABLE VIII

DISTRIBUTION OF TYPES OF VEHICLE ACCIDENTS IN THE GEOPHYSICAL INDUSTRY.

Type of Accident	1951*	1952	1953
Excessive Speed	30%	21%	22%
Backing	21%	19%	14%
Intersection	13%	12%	9%
Equipment Failure	6%	7%	5%
Passing	4%	21%	17%
Explosives		2%	0%
Collision or Upset			13%
Miscellaneous	18%	14%	13%
Total Number of Accidents	132	246	215

* 7 Months.

TABLE IX

STATISTICS SHOWING IMPROVEMENT OF GEOPHYSICAL INDUSTRY'S SAFETY RECORD SINCE 1951.

Frequency	1951	1952	1953*
All Industry	9.06	8.40	N.A.
Petroleum Industry	10.50	9.67	N.A.
Exploration Section	23.33	14.18	10.92
Contract Geophysical	53.50	27.80	22.26
Severity	**1951**	**1952**	**1953***
All Industry	.97	.88	N.A.
Petroleum Industry	1.29	1.04	N.A.
Exploration Section	1.486	.75	.98
Contract Geophysical	2.106	1.71	.41

* Partial information as submitted to the American Petroleum Institute by March 24, 1954.

The vehicular accidents reported to the exchange show a remarkable decrease in the total number of units wrecked during 1952 and 1953 when compared with the seven months of 1951. However, there were many accidents reported where the damage to the vehicles varied from $600 to $1,000. These vehicles were not considered completely wrecked, so perhaps the decrease in the totally wrecked vehicles may be only a decrease in degree of seriousness.

The geophysical operator has several major problems. The most important of these is the proper training and indoctrination of new employees, with more emphasis on safety and accident prevention. This is particularly necessary in the case of drill helpers, since experience has shown that they are injured most often, especially during the first three months after they are hired. The other main problem is to properly educate all employees to handle motorized equipment with more care and caution to prevent or decrease the large number of vehicular accidents and the many personal injury accidents due to collision, upset, or moving vehicles.

Those who have participated in this Geophysical Accident Information Exchange activity from the beginning feel very strongly that it has been worthwhile. It has been an aid in planning accident prevention measures to eliminate accidents *before* they happen.

Safety Consultation Service

The members of the Society's Standing Committee on Safety are all vitally interested in safety and accident prevention. They are ready and willing at all times to assist any geophysical organization in setting up a safety program. There have been several cases where members of the Committee have helped others to establish safety and accident prevention plans, even in spite of the fact that this was often done for organizations that were direct competitors, business-wise. It always has been the policy of the Safety Committee to consider safety and accident prevention on a non-competitive basis. The members of the Safety

Committee will continue this concept and will always be ready and willing to help anyone who desires assistance in matters pertaining to safety and accident prevention.

THE REQUIREMENTS FOR SAFE OPERATIONS

As mentioned earlier, the most important requisite for safe operations is for management to realize its responsibility for safety and accident prevention. Of course, it does not suffice to realize it for the moment and then promptly forget about it until another serious accident has occurred. It is also not sufficient for management to go out and hire a safety engineer, put him to work on the problem, and feel that thereby its responsibilities for safety have been discharged. It cannot be overemphasized that safety efforts in order to be successful must have the continued and unqualified support of management. Once this has been achieved it then becomes necessary for management to sell the importance of safety to the remainder of the organization. This effort to sell safety must succeed all the way down the chain of command in order to be successful.

It is necessary that management secure and continue employee participation in a safety program. Many companies that have been successful in their endeavor to secure employee participation have found it advisable to establish safety committees on all field parties and in shops and laboratories. Represented on these committees are employees from the various work activities, such as drilling, shooting, observing, etc., which are carried on within the unit represented by the safety committee. Regular monthly safety meetings, as well as on-the-spot safety meetings held in the field by groups of drillers, observers, shooters, and their helpers, are held successfully at regular intervals. Regular monthly inspections of all equipment, tools, and work methods by the safety committees are also an aid in maintaining employee participation.

In order to succeed with a safety program, it is also absolutely essential that the responsibility for safety be definitely established. It must be thoroughly understood that safety is an operating problem and, as such, is the responsibility of the experienced employees, party chiefs, and supervisors, and not the responsibility of a safety department or safety engineer. The safety engineer can only aid in planning various safety moves and measures, but he cannot be responsible for proper safety measures being carried out in field operations. For best results, safety engineering should be considered a staff or advisory function. Safety and accident prevention must be the responsibility of the head of the operating branch of an organization, as well as of top management.

The establishment of an efficient system of accident reports is very essential to an effective safety program. This is necessary in order to plot the progress, or the lack thereof, of a safety program at regular intervals. Safety records are also necessary to recognize bad accident-producing conditions which are responsible for the many accidents. Keeping sufficient safety records also makes it possible to recognize employees who are accident-prone and who are repeatedly injured or involved in accidents.

Even though an effective safety and accident prevention program has been established within a geophysical organization, additional benefits can be derived by cooperating with others in matters pertaining to safety and accident prevention. The recognized safety agencies, such as the American Petroleum Institute, The National Safety Council, and the Bureau of Mines, are always willing to extend a helping hand to anyone who asks for assistance. As mentioned earlier, the Committee on Safety of the Society will also cooperate in every way to further the cause of safety and accident prevention. Participation in the Geophysical Accident Information Exchange provides useful information to aid in planning effective safety measures.

The safety organizations, including the Society's Committee on Safety, have published many booklets, posters, and other safety material, all designed to secure employee interest and participation in a safety effort. These are available to any geophysical operator, usually on a non-profit basis.

RESULTS ACCOMPLISHED

During the last several years the Committee on Safety of the SEG has spent a great deal of time and effort to interest the geophysical industry in problems of safety and accident prevention. Many safety meetings have been held, papers dealing with safety problems have been published, safety posters have been made available, and safety pamphlets have been written and distributed on an industry-wide basis. As a result of all this effort, a greater interest in safety among geophysical operators has been established. The statistical results submitted to the American Petroleum Institute and the Society's business office, as shown in Table IX, indicate a remarkable improvement during 1952 and 1953. When it is realized that an improvement in these statistical figures represents a decrease in human suffering resulting from needless accidents, the efforts of all those who have worked on this problem have been worth while.

Yes, progress has been made, but it cannot be overemphasized that the two most important factors toward greater safety are the determination of management that safe operations are important and the persistence of management toward attaining the goal of safe and, as a result, profitable operations at all times. Without this determination it is almost impossible to achieve results. This safety effort is one in which the geophysical industry must succeed in order to avoid a reputation of being one of the most hazardous industries. We cannot afford to fail in our efforts to improve the rather poor performance of the past. We can succeed towards the goal of safer operations when all geophysicists in responsible management positions become aware of the fact that "safety is our responsibility."

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NEW HORIZONS*

T. S. PETERSEN†

Good morning, gentlemen. Or perhaps I should begin by saying, "Dear friends and fellow gamblers."

Of course, all of us in the oil business are gamblers of one sort or another, but none so much as you petroleum geologists and geophysicists, who tell the rest of us where to place our money on the wildcat longshots that may pay off in new producing oil fields.

The finding and producing of petroleum reserves is your business, and I have no intention of trying to discuss any of the technical aspects of that business. I do, however, want to present a broad over-all viewpoint, which may give a sense of relativity to oil exploration in the immediate future, to at least one part of the new horizons which lie just ahead of us.

In the not so distant past the prospectors of our business developed much of the early production in locations which were marked by oil seepages. These were pretty obvious evidence, even to anyone not familiar with oil operations. They were joined, and sometimes very successfully, by the wildcatters who drilled on hunches, or followed the erratic antics of a doodlebug.

To-day the obvious sites, easy to find and to drill, have long since become a part of history. And the stakes in this gambling game of oil exploration are too high for drillers who rely on luck alone. All of us who now are risking our money in the search for new oil require expert geologic counsel. We can not afford to operate without the advice of someone who picks a location on the basis of informed thinking, on the basis of his knowledge of the underground formations, on theory tempered by experience.

All this, of course, is not news to you, any more than it is to me. But bringing it again to mind at this time reminds us of the long way which we have come in a few short years. In addition, it serves to emphasize the realities of exploration at a time when we in this country need more than ever to build up our reserves. And let's remember that it is taking more skill and ingenuity, more effort and perseverance and *much* more money, than ever before.

All of the brains in this business of finding oil are not working for the big oil companies; they never have been. You know yourselves of the thousands of successful strikes which have been made by individuals and by smaller companies. This is well recognized throughout the industry, and has brought this comment from Mr. Everette DeGolyer:

"The United States oil industry has been able to produce almost two-thirds of the world's oil

* Principal address presented at the Joint Opening Session of the AAPG-SEG-SEPM Convention in St. Louis, April 12, 1954. Manuscript received by the Editor May 7, 1954.

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because of its success in prospecting for new fields. To my mind the basic and fundamental reason for such success is multiple individual effort.

"It is the thousands of American wildcatters, thousands of independent venture-minded managements, corporate and individual, who have made possible discovery at the rate required."

I will certainly buy that recognition of individual effort which Mr. DeGolyer has expressed so well. The larger, integrated oil companies have had their share of discoveries too; still, we can not overlook the enterprising individuals who brought in such notable discoveries as the West Edmond field in Oklahoma, Kettleman Hills in California, and fabulous East Texas.

There have always been success stories in the search for oil, such as the ones which lie behind the names of those fields. There will be others in the future too, as the search goes on.

The industry always has needed, and always will need, both large and small operators in almost every phase of the oil business. We are all interdependent, one upon the other. Still, we are coming into some areas of exploration where faith and ingenuity, dogged persistence and technical knowledge, are not in themselves enough.

We are coming to the new horizons, where to these attributes must be added financial backing and dollar reserves on a scale never known before. Whether or not these are to be productive horizons, economically as well as geologically, depends on many varied circumstances; and one of the most important of these is the competence of this nation's "rock hounds." I mean all of you, whether you work with a stadia rod, with a seismograph crew, with a microscope, or only with a slide rule.

In the every-day conduct of your work, you have come a long way from looking for oil seeps, from depending on surface evidence alone. The modern methods and scientific instruments which your profession has developed and utilized have become important tools in our never-ending search. However, they remain only tools.

The petroleum geologist must still make the final recommendation of where and how to drill. In the end it is on his judgment that many hundreds of millions of dollars will be risked in the era ahead of us.

There remains a great deal of work to be done if we are to continue adding to our reserves, and to our production capacity. Think of just the Williston Basin, of the development and individual discoveries yet to come in that vast landscape alone. I am confident that many of the discoveries there, and in other parts of the country as well, will credit the work of independent operators and smaller companies.

There is one large domestic area on the new horizon, however, which appears to require the resources of the larger oil companies, organizations which can put up a multi-million dollar ante before the cards are dealt, and keep on betting high stakes against long odds for an extended period of time.

This new area encompasses the submerged lands of the continental shelf, the

potential oil reserves lying in the Gulf of Mexico and off the coastline of California. It is this area that I particularly want to talk about to-day, not from the viewpoint of technical exploration, but as a problem in dollar and cents economics.

We've all heard a great deal of talk in the past several years about these submerged lands, of the millions of barrels of oil lying off the coasts of Texas and Louisiana and California. Some have made these largely untapped reserves seem like a bonanza, like a rich source of easy production just waiting there for anyone who could get a lease from one of the states, or from the Federal Government.

I think it is time that the public, and all of us in the oil industry, were made aware of the realities of offshore exploration and production. I think it is high time that the risks and expenses involved in such operations were measured against the recovery of crude oil which must be obtained if the investments we make there are to be money well spent.

To begin with, in the offshore areas, of course, you can obtain only limited surface evidence to point the way. There is little history to be read from the loggings of previous dry holes, few outcroppings to help in the locating of a subsurface structure. You are limited largely in your selection of a drilling site to the information that can be developed by instruments, by the seismograph and gravity meter. On top of all this you face the probability of never knowing exactly where you are on a stretch of open water. So at the very start the risk is increased.

An operator in the offshore area must depend pretty much on interpretation of geophysical records in his search for oil-bearing formations. And he is also limited in another direction, by the type of oil field he must find to stay in business.

In most of the oil-producing parts of this country you can get along pretty well if you just keep on finding a good ten feet of productive sand in every hole, provided you don't have to drill too deep. You can't afford to look for this kind of marginal production, however, when you're prospecting over water. You can't afford to develop fields with thin sands, or slow pay-out reserves, no matter how large they may be. It costs too much to find a field, develop it, and keep production flowing.

With these limitations existing from the beginning, and exploratory wells costing perhaps a million or more dollars apiece, you can see the reliance placed upon the petroleum geologist, upon the geophysicist, and the awareness that at these prices he can't afford to miss very often.

Leasing, of course, is another expensive item. Where a company might take wildcat land on shore at anywhere from ten cents to a couple of dollars an acre, it usually doesn't stand a chance of getting an offshore lease at anywhere near those prices.

As you may know, offshore leases are obtained on competitive bids covering large tracts of land. You can't lease this farmer's twenty acres, and that rancher's south pasture, when you're working out on the water. Your concern is with far

larger tracts, and the price you bid just for one lease would buy a great many service stations, or tank trucks, or typewriters.

As an example, let's take a look at what happened last December, when the Texas School Land Board put nearly half a million acres of submerged lands on the block. This land extended from the shoreline to points several miles offshore, at varying depths beneath the surface of the Gulf, and it was offered to bidders in tracts ranging from 640 acres to about 5,700 acres each.

The oil companies which bid successfully for these Texas leases paid an average price of $78.50 an acre. There were nine bids for individual tracts which exceeded $1 million apiece, and one company paid more than $3 million for a five-year lease on 5,700 acres. The total bonuses paid to the state of Texas for 375 of these tracts amounted to nearly $32 million.

In addition to the original price, these five-year leases carry an annual rental of $2 per acre. And the lease period of itself presents another risk, because, unless an adequate drilling program is carried out within the initial five-year period, these parcels can again be thrown open to public bid.

This Texas sale gives you an idea of what it costs just to sit down in this gambling game of looking for oil in the offshore areas. And this is only the beginning of unfamiliar circumstances, for most of these leases are in fairly deep water, 30 to 50 feet of it.

Having successfully bid for such a lease, and after expensive geophysical investigations, let's consider the steps necessary before you can even start to test its oil-producing possibilities. The governing condition is the fact that an operator with such a lease must work over water. He obviously can't just pound a marker stake into the ground, scrape out a road, and telephone the location to a contract driller.

He usually must plan and prepare to do the job himself, although there are a few contract drillers now equipped for offshore work. But no matter who does the drilling, an offshore operator will have to start out with his plans in one hand and a good-sized checkbook in the other.

Before any actual work on the water begins, the offshore operator must establish a base on land from which to work. For a single wildcat well it need not be too extensive. For prolonged operations, however, this can mean writing a check for anywhere from $200,000 to $2 million to provide for general operating headquarters, warehousing for equipment and supplies, dock facilities for boats and barges, living quarters, and a communications center that would do credit to an army regiment.

Remember that the men working out on the water can't be reached by telephone, so constant radio contact becomes a necessity. They must have food and mail, which can't be dropped off by a truck which just happens to be going that way. This means a flotilla of personnel and supply boats are a necessity, at an outlay of perhaps $1 million for the first wildcat well if you buy them, something less if you can rent the boats you need. And at least one company I know of

operates an amphibious airplane as auxiliary, emergency transportation.

Having purchased all of these things, established an operating base on dry land, and staffed it with the necessary technical personnel, the offshore operator can begin to think about drilling his well. For one small drilling platform, erected in 60 feet of water, he had better be prepared to write a check for at least $300,000. But usually he can't ferry his drillers back and forth to the platform every eight hours so provision must be made for living quarters. There's no room on a small platform for all of the drill pipe, casing, and mud that he's going to need. The answer to those problems has been found in special drilling tenders, which can be anchored close to the platform.

Some companies have bought war-surplus LST's and made them suitable for this kind of work. Others have converted surplus Navy barges. In either case, it has cost anywhere from $750,000 to more than $1 million for conversion, and if you were to start out now your outlay would be considerably greater, because there are no more of these surplus ships available. In fact, one drilling tender recently reported under construction, is being built at a cost of $2.7 million.

When all of this has been bought, if there's still any money left in the checking account, the offshore operator can spud in his wildcat and hope for the breaks. He's going to need them, in an operation where depreciation and maintenance run 25 per cent above normal costs, where it is custom for drilling crews to work 12-hour shifts for two weeks straight, much of it at overtime pay, where the operating costs for a drilling tender alone range from $1,200 to $2,500 a day, where, if he's operating in the Gulf, drilling may be curtailed, or shut down, from 5 to 10 per cent of the time because of weather.

When you add up all of these aggregate costs, necessary before completion of the first offshore well, it comes to quite a sum. To recover this investment, plus higher maintenance, producing, and crude transportation costs, the oil field that is found had better be a pretty good one.

As an actual example of what it takes in the nature of cash outlay to go exploring on the high seas, I can cite the experience of The California Company, largest producer in the Gulf of Mexico. For preliminary exploration, plus leases and equipment, The California Company paid out more than $7 million before spudding in its first offshore well in July, 1948. It had paid out some $9 million before the first oil was brought in a month later.

This, I'm sure you'll agree, is a lot of money. However, it might have been much more, because The California Company was lucky. It found two good oil fields in its first four wildcat ventures in the offshore area. You know how seldom this happens in rank wildcat territory.

With these exploratory cost figures in mind, let's take a realistic look at the future. I think it's pretty well agreed that the offshore reserves probably represent this nation's greatest single hope for maintaining production at a rate close to our increasing domestic demand.

It may be that we will never again produce all of the crude oil we are going

to need in this country. But the offshore areas, as our last great outpost of potential production, should certainly be developed as far as it is economically possible to do so.

At the present time the offshore oil fields contribute very little to the Nation's crude production total—about 12,000 B/D in the Gulf of Mexico and about 55,000 B/D from underwater fields adjacent to the California coast.

The National Petroleum Council's extensive study of the offshore area estimates that in the next five years or so production from the submerged lands can reach a daily rate somewhere between 170,000 barrels and 200,000 barrels a day. It seems probable that over a longer length of time even greater production rates can be achieved.

If this can be done, although I don't believe it will ever close the gap between what we produce and what we use, these potential offshore reserves will be a valuable asset to our nation's productive resources. This, however, is dependent on a great many factors which must remain favorable to such oil development.

Engineers familiar with offshore operations already have been whittling away at operating costs, which so far probably have been as great a deterrent as any factor affecting exploration over the water. One example that comes to my mind is a recently-developed rig which can drill six wells from one platform position without being moved.

There are other changes being made all the time, in equipment and in operating procedures, which contribute to more economical operations. Such improvements will continue to be made by the operating companies as they pile up additional experience in this kind of work. There will have to be such improvements if the offshore reserves are to be economically attractive.

Just remember that oil produced from under the sea brings no greater price in the market, has no greater value to the refiner, just because it costs three times as much to find it, produce it, and get it to a shipping point.

Another important factor, and I don't believe this can be over emphasized, is the necessity for unusually competent geologic counsel. The geologist picking a drillsite on a flat stretch of water has only a few geophysical and geological signposts to guide him. And when he has made his decision he knows it is going to cost someone a great deal of money to find out if he made the right selection.

Under these circumstances, the offshore rock hound must be just about as good as they come.

Behind the geologists and the engineers, there must be operators of adequate financial size to lay out the money it takes to get started in the offshore areas. They must also be operators working with a long-range view, for offshore development takes time as well as money.

Standing as witness to the necessity for these characteristics are two figures. One of these is $260 million, the amount which it was estimated last year the oil industry had invested in the Gulf of Mexico. The other figure is $50 million, the total return to date on this investment, which began to build up back in the 1930's.

To the sum of these must be added other factors, which probably can best be grouped under the singular heading of incentives. They comprise the favorable conditions which must exist if the offshore areas are to be developed to their greatest potential.

Foremost among these is the matter of an adequate price structure for crude oil, in other words, a price incentive. It is significant that the oil industry made no real attempt to develop coastal fields while the price of crude oil remained relatively low.

I believe that more than coincidence marks the fact that 1947 was the year in which several major oil companies began to go after offshore production in earnest, and was the year in which the price of 34° gravity Gulf Coast crude rose from $1.81 a barrel to $2.76 a barrel as price controls were removed. This same crude oil today is quoted at $3.11 a barrel. It must remain at a stable and favorable level if we are to continue development of these potential producing fields.

All of the attempts at finding offshore production haven't been favorable, by any means. There is no reason to believe that they will be more so in the future. This being the case, it is necessary that the industry be granted continuance of the exploration incentive represented by the 27½ percent depletion tax provision.

As you are surely aware, there has been considerable political agitation in Washington during the past few years to decrease considerably—or even eliminate entirely—this allowance which enables us to keep on gambling with wildcat exploration programs. If this should happen, if this incentive were reduced or removed, you can be sure that there would be a great inclination to forget the offshore reserves entirely, and to turn further toward foreign petroleum sources.

Because much of the potential production in the Gulf of Mexico lies within the borders of Texas and Louisiana, another incentive will stand or fall according to the allowable production rates set by those two states. This applies also to federal lands beyond their historic boundaries.

I spoke a few moments ago of the necessity for finding oil fields which are relatively prolific producers in order that the return from the sale of their oil might be counted on to pay out the large investment required to bring them into production. It is just as necessary, and for the same reason, that state and federal regulatory bodies continue to recognize this economic reality, as the state of Louisiana has done, and set allowables for the offshore fields which are high enough.

The same sort of cooperation must be forthcoming from the state and federal governments in their leasing agreements on the submerged lands. Without it, these leases can effect various limitations on oil operators which will amount to the same thing as these governments pricing themselves right out of the oil royalty market.

Development of California's submerged lands will also depend in large part on the favorable cooperation of state and municipal bodies. At the present time, under existing California law, the State Lands Commission may only lease submerged lands when these areas are being drained, or are threatened with drain-

age, from existing fields. In addition, oil operators are only permitted to drill into these submerged lands from onshore sites, from filled lands, or existing piers. Naturally, this law as it stands now severely limits the wildcat areas which the state is able to lease.

A further deterrent on the West Coast is the present practice of imposing a sliding scale of royalty payments, ranging from 12.5 to 45 percent, depending on the rate at which a well or a field is produced.

These provisions of the California law must certainly be amended if there is to be any extensive wildcat exploration of the reserves lying off the West Coast.

This has been a fairly long recital of conditions which will govern the success of our development of the offshore areas. I realize that in some respects it may serve to dim the rosy picture of these areas as it is painted for the public by some. Still, I firmly believe that we should set out these conditions for all to see, and do our best to make the favorable ones come about while attempting to overcome those which may be unfavorable.

Unless we can do this, these valuable reserves may largely remain unproduced for many years to come. Given favorable conditions, the development of these offshore lands will become a noteworthy achievement by our industry, and one which will benefit the American economy for many years in the future.

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ANNUAL SURVEY OF GEOPHYSICAL EDUCATION, 1953–1954*

The shortage of professionally trained geophysical engineers, as of all types of engineers, continues to be acute. In spite of the encouraging growth of offerings in the field of geophysical education, the needs of industry, government and the universities are such as to induce a degree of competition for available man power that is far from healthy.

There has been no increase in the number of departments of geophysics and geophysical engineering over the seven reported last year. A total registration of 3,492 in geophysical courses (including meteorology) was reported by 65 educational institutions. The number of undergraduate students whose major field is geophysics, geophysical engineering or meteorology is 364, and the number of graduate student majors is 338.

The total number of bachelors' degrees in geophysics given between July, 1952 and June, 1953 was 113. The number of masters' degrees conferred in the same period was 47. Doctors' degrees in geophysics conferred in this same period were as follows:

California Institute of Technology	2
University of California (Berkeley)	1
University of California (Los Angeles)	1
Columbia University	1
Johns Hopkins University	1
University of Oklahoma	1
Saint Louis University	3
Texas A & M College	2
Toronto, U. of	3

The details of courses and administration in the 72 institutions which answered the questionnaire are given in Tables I and II. In each case the number of semester or quarter courses on the elementary (E), advanced (A), and graduate (G) levels devoted exclusively to the given field and actually taught in the summer of 1953 or the year 1953–1954 are given under the respective column headings.

* Presented at the Annual Business Meeting of the Society at St. Louis, Missouri, April, 1954 by Reverend James B. Macelwane, S. J., Chairman of the Education Committee. The other members of the Committee are Perry Byerly, Beno Gutenberg, John C. Hollister, M. King Hubbert, Sherwin F. Kelly, D. C. Skeels, and H. W. Straley, III.

TABLE I

Institution	Administration		Students in Applied Geophysics				Titles of Geophysical Degrees	Degrees Conferred July 1952–June 1953			Faculty Teaching Courses in Geophysics
			Total in Courses 1952–1953		Majors						
	Departments	Schools or Colleges	I	II	Undergraduate	Graduate		Bachelor's	Master's	Doctor's	
Alaska, U. of	Geophysics	—	7	14	1	2	B.S.,[1] M.S.,[1] Ph.D.[1]	—	—	—	3
Arizona, U. of	Physics	Liberal Arts	7	—	—	—	—	—	—	—	1
Arkansas, U. of	Physics & Geology	Arts & Sciences	—	—	—	—	—	—	—	—	2
Brigham Young U.	Geology	—	—	10	—	—	—	—	—	—	1
Brown U.	Oceanography	—	4	—	—	—	—	—	—	—	1
Calif. Inst. of Tech.	Division of Geological Sciences	—	38	36	5	12	Geophysical Engineer, M.S., Ph.D.	1	3	2	5
Calif., U. of (Berkeley)	Geological Sciences	Letters & Science	26	22	12	8	A.B., M.A., Ph.D.	7	3	1	3
Calif., U. of (Los Angeles)	Geology, Physics	Letters & Science	16	9	21	9	B.A.,[2] M.A.,[3] Ph.D.[3]	3	1	1	5
Colorado A & M Col.	Civil Engineering	—	25	25	—	—	—	—	—	—	5
Colorado Sch. of Mines	Geophysics	—	76	168	109	14	Geophysical Engineer, M.S., D.Sc.	33[4]	3	—	4
Colorado, U. of	Geology	Arts & Sciences	17	18	—	—	—	—	—	—	1
Columbia U.	Geology	Graduate Faculty	12	14	—	8	M.A., Ph.D.	—	1	1	3
Florida State U.	Meteorology, Geology	Arts & Sciences	239	292	12	14	.BS.,[5] M.S.[5] Ph.D.[5]	7	—	—	7
Franklin & Marshall Col.	Geology	—	—	—	—	—	—	—	—	—	1
Georgia Inst. of Tech.	Geology, Physics	Ceramic Engineering	1	1[6]	15	—	B.S.[7]	—	—	—	5
Houston, U. of	Geology, Physics	Arts & Sciences	55	23	—	—	—	—	1	—	2
Illinois, U. of	Mining & Metallurgical Engineering, Geology	Engineering, Liberal Arts, & Sciences	13	—	—	—	—	—	—	—	1
Johns Hopkins U.	Geology, Oceanography, Civil Engineering	—	12	23	—	12	M.A.[8]	—	5	1	6
Kansas City, U. of	Geology & Geography	Liberal Arts	—	21	—	—	—	—	—	—	2
Kansas State Col.	Physics & Geology	Arts & Science	10	10	5	—	—[9]	—	—	—	1
Lehigh U.	Mining Engineering	Engineering	3	3	3	—	B.S.[10]	2	—	—	1
McMaster University	Geology	Hamilton	6	6	—	—	—	—	—	—	1
Mass. Inst. of Tech.	Geology & Geophysics	Science	47	44	21	24	B.S.,[11] M.S.,[11] Sc.D.,[11] Ph.D.[11]	9	—	—	1[12]
Miami U.	Geology	Arts & Sciences	10	—	—	—	—	—	—	—	1
Michigan, U. of	Geology	Literature, Science & Arts	30	12	—	5	—	—	2	—	2
Michigan Col. of M. & T.	Physics	—	23	35	—	1	M.S.[13]	—	1	—	2
Michigan State College	Physics & Astronomy	Science & Arts	32	—	—	—	—	—	—	—	1
Minnesota, U. of	Geophysics	Mines	25	22	6	1	Bachelor of Geophysics,[14] M.S.	1	—	—	1
Mississippi State Col.	Physics	Science	—	22	—	—	—	—	—	—	1
Montana Sch. of Mines	Physics	Mines	—	6	—	—	—	—	—	—	1
Nevada, U. of	Civil Engineering	Engineering	8	—	—	—	—	—	—	—	1
New York U.	Meteorology, Oceanography, Geology	Engineering & Graduate	58	56	15	36	B.Sc., M.Sc., Ph.D., M.A.[15]	—	1[16]	—	1
North Carolina, U. of	Geology & Geography	—	—	16	—	—	—	—	—	—	1
North Dakota, U. of	Geology, Geography (Meteorology)	Engineering, Science, Literature & Arts	4	4	—	—	—	—	—	—	3
Northwestern U.	Geology	Liberal Arts	4	4	—	—	—	—	—	—	1
Ohio State U.	Geology	Arts & Sciences, Institute of Geodesy, Photogrammetry, & Cartography	17	16	2	9	B.S.,[17] M.S.,[17] Ph.D.[17]	—	1	—	3

[1] In Geophysics.
[2] In Earth Physics and Applied Geophysics.
[3] In Geology, Physics, Chemistry, Meteorology.
[4] Geophysical Engineer.
[5] In Meteorology.
[6] Quarters, 20 anticipated in 3rd quarter.
[7] In Physics, Geophysics Option beginning June, 1954.
[8] Oceanography.
[9] Physical Science (Geophysics Option).
[10] In Mining Engineering (Engineering Geophysics Option).
[11] In Geophysics.
[12] Plus 5 Instructors and Research Associates.
[13] In Geophysics.
[14] Five Year Undergraduate Curriculum.
[15] In Geology with courses in Geophysics.
[16] In Geology with courses in Geophysics.
[17] In Geodetic Science.

[7] In Physics, Geophysics Option beginning June, 1954.
[8] Oceanography.
[9] Physical Science (Geophysics Option).
[17] In Geodetic Science.

TABLE I—*Continued*

Institution	Administration		Students in Applied Geophysics				Titles of Geophysical Degrees	Dgerees Conferred July 1952–June 1953			Faculty Teaching Courses in Geophysics
			Total in Courses 1953–1954		Majors						
	Departments	Schools or Colleges	I	II	Undergraduate	Graduate		Bachelor's	Master's	Doctor's	
Oklahoma, U. of	Physics, Geology	Arts & Sciences, Engineering-Graduate	—	18	5	2	—	5[18]	1[18]	1[18]	1
Oregon State Col.	Geology, Physics	Science	—	3	—	—	—	—	—	—	1
Pennsylvania State U.	Division of Geophysics & Geochemistry	Mineral Industries	94	101	24	17	B.S., M.S., Engineer of Mines, Ph.D.	2	4	—	7
Pittsburgh, U. of	Geology & Electrical Engineering	—	30	30	—	—	—	—	—	—	2
Redlands, U. of	Geology	—	15	—	5	—	B.S.[19]	15	—	—	1
Rensselaer Poly. Inst.	Geology	Science Group	3	9	—	—	B.S.[20]	—	—	—	1
Saint Louis U.	Geophysics & Geophysical Engineering	Institute of Technology, Graduate	341	368	52	71	B.S.,[21] M.S.,[22] Ph.D.,[22] B.S.,[23] M.S.[24]	20	9	3	6[25]
San Jose State Col.	Natural Science	—	—	—	—	—	—	—	—	—	3
Saskatchewan, U. of	Physics	Arts & Science	—	—	—	—	—	—	—	—	—
Southern Calif., U. of	Geology, Engineering	—	—	—	—	—	—	—	—	—	1
South Dakota, U. of	Geology	Arts & Sciences	—	—	—	—	—	—	—	—	1
Southern Methodist U.	Geology	Arts & Sciences	7	—	—	—	—	—	—	—	—
Tennessee, U. of.	Geology-Geography	—	10	—	—	—	—	—	—	—	3
East Tennessee State Col.	Geography	—	36	21	—	—	—	—	—	—	15
Texas A & M Col.	Oceanography	Arts & Sciences	145	131	14	27	M.S.,[26] Ph.D.[26]	—	4	2	1
Texas Christian U.	Physics	Arts & Sciences	9	20	—	—	—	—	—	—	3
Toronto, U. of	Physics	—	13	13	4	12	B.A.Sc.,[27] M.A., Ph.D.	—[28]	1	3	1
Tulane U.	Geology	Arts & Sciences	15	11	—	—	—	—	—	—	1
Tulsa, U. of	Physics & Geophysics	Engineering & Liberal Arts	25	30	20	—	B.S.[29]	5	—	—	2
Utah, U. of	Geophysics	Mines & Mineral Industries	15	28	9	4	B.S.,[30] M.S.,[30] Ph.D.[30]	3	2	—	1
Washington U.	Geology & Geological Engineering	Liberal Arts, Engineering	16	7	—	5	A.M.,[31] Ph.D.[31]	—	3	—	1
Washington, U. of	Geology	Arts & Sciences	8	—	—	2	—	—	—	—	1
Wayne U.	Geology	Liberal Arts	—	—	—	—	—	—	—	—	1
Western Ontario, U. of	Geology, Physics	Arts & Sciences	4	4	—	1	B.Sc.,[32] M.Sc.,[32] B.Sc.,[33] M.S.,[33] Ph.D.[33]	—	—	—	1
Western Reserve U.	Geology[34]	—	—	—	—	—	—	—	—	—	1
Wichita, U. of	Geology	Liberal Arts	—	—	—	—	—	—	—	—	1
Wisconsin, U. of	Geology, Meteorology, Civil Engineering	Letters & Science, Engineering	75	60	4	12	B.S.,[35] M.S.,[35] Ph.D.[35]	—	1	—	3
Wyoming, U. of	Geology, Physics	—	10	10	—	—	— —	—	—	—	—
Xavier U.	Physics	—	—	—	—	—	—	—	—	—	1

[18] Physics or Geology.
[19] In Geology.
[20] In Geology (Geophysics Option).
[21] In Geophysical Engineering.
[22] In Geophysics.
[23] In Professional Meteorology.
[24] In Meteorology.
[25] Not including 7 Graduate Fellows.
[26] In Oceanography (Physical, Chemical, Biological, Geological, and Meteorological).
[27] In Engineering Physics.
[28] Degree given as Arts or Engineering degree.
[29] In Geophysical Engineering.
[30] In Geophysics.
[31] In Geology.
[32] In Geology with Geophysics Option.
[33] In Physics with Geophysics Option.
[34] An occasional elementary course in Meteorology.
[35] In Geology (Geophysics Option).

TABLE II

Number of Semester or Quarter Courses Actually Taught, Summer 1953 to Spring 1954
E = Elementary Course; A = Advanced Undergraduate Course; G = Graduate Course

Institution	Field Covered by Courses																		
	General Geophysics	Geophysical Theory	Geophysical Exploration (several methods)	Seismic Exploration	Gravity Exploration	Magnetic Exploration (including airborne)	Geochemical Exploration	Electrical and Electromagnetic Exploration	Other Geophysical Methods of Exploration	Earthquake Seismology	Geo-Electricity	Geomagnetism	Geodesy	Geophysical Electronics	Hydrology	Meteorology	Physical Oceanography	Volcanology	Other
Alaska, U. of	6E											18G				1E			14G
Arizona, U. of																			
Brigham Young U.			2E																
Brown U.																½E	½E		
Calif. Inst. of Tech.	1E		1A							1A									
	1G	2G		1G	1G	1G				1G									2G
Calif., U. of (Berkeley)		1A	1A	1A						1A									
		1G								4G								1G	
Calif., U. of (Los Angeles)			1A								1A								
		1G						1G			1G								2G
Colorado A & M Col.															4E	3E			6E
															3A				3A
Colorado School of Mines		2E	2E																
		2A	1A	1A	1A	1A		1A						1A					
		2G	1G	1G		1G													
Colorado, U. of			2E																
Columbia U.	1G		1G							1G						2E			2G
Cornell U.																1E	1E		
Drake U.																1E			
Florida State U.																4E			
																10A	2A		
																9G	1G		
Georgia Inst. of Tech.	1A		1A		1G	2A		1A											
Houston, U. of	3E		6A					3A											
Illinois, U. of			1E													1E			
																2A			2A
																1G			2G
Johns Hopkins U.	1A														1G	1G	6G		
Kansas City, U. of																3A			
																3E			
Kansas State Col.	2A																		
Kent State U.																1E			
Lehigh U.	1E		1E	½A	½A	½A		½A											
McMaster U.	1E																		
Marshall Col.																1E			
Mass. Inst. of Tech.	2G	2G	1E	1A			1A		1G										
Miami U.			1E																
Michigan, U. of																1E			
	1A												1½A		3A	1½A			
	1G		2G																
Michigan Col. of M. & T.	1E		3A						1A										
		1G							1G										
Michigan State Col.	1E															1E			
Milwaukee-Downer Col.																1E			
Minnesota, U. of	1E		1E	1A	½A	½A		1A		1E									1G
Mississippi State Col.			1E																
Montana Sch. of Mines	1E																		
Nevada, U. of															1E				
New Hampshire, U. of																2E			
New York U.																1E			
																10A	1A		
	2G															15G	6G		

TABLE II (*continued*)

Institution	Field Covered by Courses																			
	General Geophysics	Geophysical Theory	Geophysical Exploration (several methods)	Seismic Exploration	Gravity Exploration	Magnetic Exploration (including airborne)	Geochemical Exploration	Electrical and Electromagnetic Exploration	Other Geophysical Methods of Exploration	Earthquake Seismology	Geo-Electricity	Geomagnetism	Geodesy	Geophysical Electronics	Hydrology	Meteorology	Physical Oceanography	Volcanology	Other
North Carolina, U. of			1E							1E						8E			6E
North Dakota, U. of	4E						4E												
Northwestern U.	2A															1E			
Ohio U.													1E						
Ohio State U.													1A						
	1G												3G						
Oklahoma, U. of			1A											1A					
Oregon, U. of																4E			
Oregon State Col.	1E																		
Pennsylvania State U.	2A		2A					2A											1A
	1G																		7G
Pittsburgh, U. of	1E															1E	1E		1G
Redlands, U. of	2E		2E																
Rensselaer Poly. Inst.	1E	1E	1E																
Saint Louis U.	1E																		
	1A	5A	4A							4A				2A		13A			
	4G	2G	1G							3G						7G			
San Jose State Col.																9E			3E
																			3E
																6A			
Saskatchewan, U. of											4G*					4E			
Southern Calif., U. of															3G		2G	1G	
South Dakota, U. of																1E			
Southern Methodist U.	3E																		
Tennessee U.																1E			
East Tennessee State Col.																3E			2E
Texas, A & M Col. of																6E			
																2A	2A		2A
																2G	7G		5G
Texas Christian U.			1E																
Toronto U.	1A	1A	1A	1A	1A			1A		1G						1G			1G
Tulane U.			1E						1E										
Tulsa, U. of	2E			1A	1A	½A		½A						1A					1A
Utah, U. of			1E	½E	½E	½E	½E	½E							3E				
				1A	1A	1A		1A											
Washington U.			1A																
			1G	1G	1G	1G		1G											1G
Washington, U. of										1E									
										1A								1A	
George Washington U.																3E			
Wayne U.																3E			
Western Ontario, U. of	1A		1A																
		1G	1G																
Wichita, U. of	3G																		
Wisconsin, U. of	1E		1E												2E	1E	1E		
															1A	2A			
	1G	1G														2G			
Wyoming, U. of															1A	1E	1G		

* Problems in Physics of the Upper Atmosphere (including geomagnetism).

DEPARTMENTS

PATENTS

O. F. RITZMANN*

MAGNETIC PROSPECTING

U. S. Re. 23,769 (Original No. 2,561,490). R. H. Varian. Iss. 1/12/54. App. 10/21/48, 7/24/51 and 7/11/52. Assign. Varian Associates.

Method and Means for Correlating Nuclear Properties of Atoms and Magnetic Fields. A magnetometer in which a strong polarizing field is periodically applied to a sample of material with nuclear gyromagnetic moment at an angle to the field to be measured and the precession frequency of the nuclei measured immediately after removal of the polarizing field.

U. S. No. 2,671,275. L. L. Burns, Jr. Iss. 3/9/54. App. 3/31/49. Assign. Radio Corporation of America.

Magnetometer. A magnetometer having a variable-permeability core with a coil connected in an oscillating circuit whose frequency is compared with a standard, or a direction indicator having two perpendicular cores with coils connected in oscillating circuits whose frequencies are compared with a discriminator circuit.

SEISMIC PROSPECTING

U. S. No. 2,660,716. D. M. McFarland. Iss. 11/24/53. App. 5/6/50. Assign. Atlas Powder Co.

Method and Apparatus for Ascertaining Time of Explosion. A circuit for recording shot moment in which a potential is applied between the firing circuit and the shell of the electric detonator or to ground, and the conduction through this circuit at detonation recorded by the oscillograph.

U. S. No. 2,665,896. F. J. Kirby and W. E. Vore. Iss. 1/12/54. App. 5/6/52.

Variable Resistance Acceleration Sensitive Device. An accelerometer having a mass suspended on a cantilever spring and immersed in an electrolyte, the change in resistance between the end of the mass and a stationary electrode being observed.

U. S. No. 2,667,531. K. W. McLoad. Iss. 1/26/54. App. 12/27/49. Assign. Socony-Vacuum Oil Co., Inc.

Swivel Coupling for Seismic Surveying Systems. A strain-carrying swivel for use where a marine seismic cable enters or leaves a geophone case, the case being provided with a fork which is pivoted with a similar fork clamped to the strain elements of the cable.

U. S. No. 2,667,625. G. Peterson. Iss. 1/26/54. App. 8/24/48. Assign. Phillips Petroleum Co.

Radio Seismic System. A system for transmitting seismometer signals by radio having a transmitter at each seismometer, receiving all the radio signals at the recording station, mixing the received signals with a number of local oscillator signals, separating the respective seismometer signals by tuned intermediate amplifiers, detecting the respective signals and amplifying and recording them.

* Gulf Oil Corporation, Patent Department.

U. S. No. 2,667,812. W. W. Miller. Iss. 2/2/54. App. 6/9/50. Assign. William Miller Instruments, Inc.

Timing Light Control for Oscillographs and the Like. A timing line motor having geared rotating shutter disks with various sizes of slots through which the timing light passes when the slots are coincident.

U. S. No. 2,668,282. O. C. Montgomery. Iss. 2/2/54. App. 9/20/48. Assign. Phillips Petroleum Co.

Transmitter for Radio Seismic Systems. A radio system for transmitting shot moment in which the blasting cap frequency modulates an audio oscillator which amplitude modulates the r-f carrier, the channel being used for other communication by amplitude modulation of the r-f, and the shot moment signal detected by a discriminator at the recording point.

U. S. No. 2,670,926. B. W. Sewell and J. M. Camp. Iss. 3/2/54. App. 8/9/51. Assign. Standard Oil Development Co.

Seismograph Cable Handling Device. A cable-handling device having two opposing pneumatic tires with engaging treads with power applied to one or both through a slip clutch, the cable being pulled between the treads and collected in a random pile beneath the device.

U. S. No. 2,672,204. T. C. Poulter. Iss. 3/16/54. App. 8/30/49. Assign. Institute of Inventive Research.

Method and Apparatus for Seismic Exploration. A system of shooting above ground in areas where the frequency of reflections varies with depth in which shots are spaced or fired in time sequence so as to apply impulses to the ground which will have the proper frequency for a desired depth.

U. S. No. 2,672,813. W. P. Conner. Iss. 3/23/54. App. 4/1/48. Assign. Hercules Powder Co.

Method of Firing Electric Detonators and Circuit Therefor. A method of firing an electric detonator by connecting a small condenser and inductance to the bridge wire to form a resonant circuit which is energized by an antenna to which an r-f signal is directed from the firing point.

U. S. No. 2,672,944. J. P. Minton. Iss. 3/23/54. App. 11/4/48. Assign. Socony-Vacuum Oil Co., Inc.

Method and Apparatus for Recording Seismic Signals. A seismic filtering and recording system in which the geophone signal is amplified, filtered and recorded on an endless magnetic tape which is automatically played back into the same filter and re-recorded on the magnetic tape and also a permanent record made, the process being automatically repeated so that any desired degree of sharply-filtered record may be obtained.

U. S. No. 2,673,899. O. C. Montgomery. Iss. 3/30/54. App. 9/23/49. Assign. Phillips Petroleum Co.

Automatic Volume Control System. A seismograph avc having two avc circuits fed from the output, one having a long time constant and a tube biased beyond cut-off so that it operates only on the high amplitude first arrivals, and the other having a short time constant and a tube biased near cut-off so that it also operates on strong reflections.

WELL LOGGING

U. S. No. 2,655,631. J. E. Walstrom. Iss. 10/13/53. App. 4/28/51. Assign. California Research Corp.

Method and Apparatus for Detecting Fluid Movement in Well Bores. An open-ended conducting cylinder with an inner insulating sleeve on which are mounted two electrodes connected to the surface by a cable, one electrode being in physical contact with the well fluid and the other encased in a porous insulating sheath which permits ionic contact to the well fluid, and both electrodes shielded by the outer cylinder.

U. S. No. 2,658,725. J. J. Arps. Iss. 11/10/53. App. 10/31/47.

Signal Transmission System for Use in Logging Drill Hole Formations. A system of logging while drilling in which a radioactive material is electrolytically dissolved into the mud stream at the drill in proportion to the parameter being logged and the concentration of radioactive material in the mud is measured and recorded at the surface.

U. S. No. 2,665,187. M. M. Kinley and J. C. Kinley. Iss. 1/5/54. App. 4/15/49.

Device for Making Permanent Records. A well surveying recorder whose chart is a Lucite cylinder on which a stylus scribes a spiral record by having the chart cylinder geared to a lead screw which carries the stylus.

U. S. No. 2,665,385. G. Herzog. Iss.1/5/54. App. 12/29/48. Assign. The Texas Co.

Radioactivity Well Logging. A neutron-gamma ray logging system in which the formations are bombarded with neutrons and the decay rate of induced gamma activity subsequently measured.

U. S. No. 2,665,386. S. Krasnow and M. J. Test. Iss. 1/5/54. App. 10/1/41 and 1/30/51. Assign. Schlumberger Well Surveying Corp.

Well Radioactivity Logging Apparatus. A radioactivity logging apparatus having a Geiger-Muller tube detector whose voltage is supplied solely by a well-insulated condenser which is given sufficient charge at the surface prior to making the logging run.

U. S. No. 2,666,142. G. Herzog and K. C. ten Brink. Iss. 1/12/54. App. 3/28/50. Assign. The Texas Co.

Method of Testing Borehole Logging Instruments. A method of calibrating a neutron logging apparatus by surrounding it with a mass of sand, varying the hydrogen concentration in the pore space, and simultaneously varying the bulk density of the mass by introducing a non-hydrogenous liquid having the same bulk density as sand.

U. S. No. 2,666,146. G. Herzog. Iss. 1/12/54. App. 3/17/50. Assign. The Texas Co.

Method and Apparatus for Bore Hole Logging. A neutron-gamma ray logging system in which the detected pulses are amplified and reduced in number by a fixed proportion and the reduced number of pulses amplified and transmitted to the surface and recorded.

U. S. No. 2,667,109. R. G. Piety. Iss. 1/26/54. App. 10/9/50. Assign. Phillips Petroleum Co.

Camera Assembly for Photographing Cavity Walls. A borehole camera having a flashing light source, optical system and camera in a case with a flexible transparent window which is pressed against the formation wall by pressure of a clear liquid inside the case.

U. S. No. 2,667,583. G. Herzog. Iss. 1/26/54. App. 2/3/51. Assign. The Texas Co.

Analysis of Subsurface Formations by Radioactivity. A neutron logging system in which the formations are bombarded with neutrons and the ratio of low-energy scattered neutrons to high-energy scattered neutrons is observed.

U. S. No. 2,667,626. D. W. Blancher. Iss. 1/26/54. App. 1/23/50. Assign. Bendix Aviation Corp.

Telemetering System for Wells. A system for telemetering stress and motion of a well pump in which the sucker rod string or tubing string are insulated and used as electrical conductors to transmit an f-m signal to the surface.

U. S. No. 2,669,688. H-G. Doll. Iss. 2/16/54. App. 10/18/49 and 5/29/53. Assign. Schlumberger Well Surveying Corp.

Resistivity Apparatus for Obtaining Indications of Permeable Formations Traversed by Boreholes. An electric logging apparatus having a series of electrodes on a spring arm pressed against the bore-

hole wall, one set of electrodes having very short spacing to measure filter-cake resistivity and another set of electrodes having a larger spacing so that its measurement is influenced by the formations, the thickness of filter cake being indicative of formation permeability.

U. S. No. 2,669,689. H-G. Doll. Iss. 2/16/54. App. 4/13/45. Assign Schlumberger Well Surveying Corp.

Method and Apparatus for Determining Earth Formation Factors. An electric logging system having electrodes on a spring arm pressed against the borehole wall and spaced to measure resistivity of invaded formations and also having electrodes in the well fluid to give mud resistivity, an automatic contact being provided on the spring arm which indicates when its electrodes lose contact with the formation as in a caved region.

U. S. No. 2,669,690. H-G. Doll. Iss. 2/16/54. App. 10/18/49. Assign. Schlumberger Well Surveying Corp.

Resistivity Method for Obtaining Indications of Permeable Formations Traversed by Boreholes. An electric logging method of determining permeability from the thickness of filter cake determined by measuring the resistivity with closely-spaced electrodes pressed against the borehole wall.

U. S. No. 2,669,872. D. G. Hartweg. Iss. 2/23/54. App. 6/17/52. Assign. Dow Chemical Co.

Detection of Fluid Movement in Wells. A detector for fluid movement having two equal thermally-sensitive resistors of different size and shape each with a half-wave rectifier in series and connected in parallel with a meter at the surface which detects variations in the ratio of the two heating currents caused by fluid flow.

U. S. No. 2,670,442. G. Herzog. Iss. 2/23/54. App. 4/25/50. Assign. The Texas Co.

Radioactivity Borehole Logging Apparatus. A radioactivity logging system using a source of neutrons and gamma rays with the induced gamma-ray or neutron activity measured close to the source and the natural gamma-ray activity simultaneously measured some distance from the source.

U. S. No. 2,670,547. I. Murata. Iss. 3/2/54. App. 8/13/51.

Instrument for Measuring Dip and Orientation of Deep Wells. A well surveying instrument having a pointed pendulum and a compass magnet on the record disk, and a two-stage timing mechanism which slowly clamps the magnetically-oriented record disk and then strikes it against the pendulum point to make an impression.

U. S. No. 2,671,323. B. E. Richert. Iss. 3/9/54. App. 3/15/51. Assign. Sun Oil Co.

Apparatus for Cooling Well Surveying Instruments. A cooling system for a well surveying instrument in which the instrument is surrounded by coils of tubing forming a boiler containing a liquid which boils at operating temperature and whose vapors are passed through a refrigerated condenser and returned to the boiler.

U. S. No. 2,671,346. T. A. Banning, Jr. Iss. 3/9/54. App. 5/28/46.

Measuring and Recording Various Well Drilling Operations. A drilling-rate recorder in which the time required to drill an interval is recorded and time counting is automatically discontinued when either mud pressure, torque, power, or bit weight is below a selected value to take time out for off-bottom operations.

U. S. No. 2,672,050. B. W. Sewell. Iss. 3/16/54. App. 3/8/50. Assign. Standard Oil Development Co.

Apparatus for Locating Uncemented Portions of Well Casings. An apparatus for testing whether casing has cement behind it or not and having diametrically-opposing rollers which are periodically forced against the casing by a hydraulic piston and their relative deformation hydraulically measured and recorded.

U. S. No. 2,673,299. S. Krasnow. Iss. 3/23/54. App. 9/16/50. Assign. Schlumberger Well Surveying Corp.

Shielded Borehole Radioactivity Logging Apparatus. A radioactivity logging apparatus in which the detector is surrounded by a heavy metal shield having truncated pyramidal depressions pointing outward so as to attenuate radiation from the nearby borehole material with respect to radiation from the more distant formation.

MISCELLANEOUS

U. S. No. 2,665,237. R. J. Strawinski. Iss. 1/5/54. App. 5/8/50. Assign. Texaco Development Corp.

Prospecting. A bacteriological prospecting method in which nutrient salts are added to the soil samples which are then treated with a mixture of hydrocarbon gas and oxygen and the hydrocarbon consumption measured.

U. S. No. 2,665,332. E. A. Weiss and J. R. Wright. Iss. 1/5/54. App. 11/25/49. Assign. Sun Oil Co.

Magnetic Measuring Method and Apparatus. A magnetic core-testing apparatus in which the core is rotated adjacent to a small saturable-core gradiometer whose output is demodulated and recorded.

U. S. No. 2,665,499. R. T. Cloud. Iss. 1/12/54. App. 4/3/48. Assign. North American Geophysical Co.

Pendulum and Acceleration Compensation Apparatus. A vehicle-transported elevation-difference meter having a disc-type pendulum of electrically-conducting material suspended between a coil which is excited by an oscillator and two coils which are excited at different phases through a discriminator controlled by a generator on the vehicle wheel so that the interaction of the eddy currents in the disc produces a torque which compensates translatory accelerations.

U. S. No. 2,666,992. R. T. Cloud. Iss. 1/26/54. App. 6/7/48. Assign. North American Geophysical Co.

Elevation Meter. A vehicle-transported elevation-difference meter which has a pendulum with a photoelectrically-controlled follow-up mechanism on the same axis, pendulum motions due to translatory accelerations of the vehicle being compensated and the sine of the pendulum angle to the instrument frame being integrated.

U. S. No. 2,668,437. O. G. Patch. Iss. 2/9/54. App. 1/12/51. Assign. Clara L. Patch.

Apparatus for Metering Entrained Air or Gas by Pressure Observations. A device for determining gas in a sample of material having a cylinder of compressed air which is released into a sample container and the change of pressure in the container observed.

U. S. No. 2,673,031. R. G. Piety. Iss. 3/23/54. App. 1/2/53. Assign. Phillips Petroleum Co.

Simulator. A mechanical analogue of a well pumping system having three pairs of vertical flexible lines carrying horizontal oscillating bars to represent segments of the sucker rods, oil column and tubing, with the bars representing mass, the couple in each pair of lines representing elasticity, and viscous coupling between bars representing friction, a stepless pawl being used to integrate and indicate motion of the oil.

SELECTED LIST OF U. S. PATENTS ISSUED DURING THE FIRST QUARTER OF 1954*

Patent No.	*Subject*	*Patent No.*	*Subject*	*Patent No.*	*Subject*
2,664,742	412	2,666,576	68	2,668,662	68
2,664,748	200	2,666,620	80	2,668,878	224
2,664,750	288	2,666,854	324	2,668,879	224
2,664,779	420	2,666,857	308	2,669,034	324
2,664,917	288	2,666,862	12, 140	2,669,121	148
2,664,998	308	2,666,890	308	2,669,122	200
2,665,065	68	2,666,896	140	2,669,123	200
2,665,066	68	2,666,897	188	2,669,124	288
2,665,068	68	2,666,914	316	2,669,125	288
2,665,069	68	2,666,992[a]	444	2,669,213	288
2,665,186	148	2,667,063	140, 12	2,669,501	324
2,665,187[a]	324, 520	2,667,070	140	2,669,666	484
2,665,237[a]	172, 28	2,667,071	428	2,669,688[a]	116
2,665,331	40	2,667,072	148	2,669,689[a]	116
2,665,332[a]	88, 228	2,667,109[a]	280	2,669,690[a]	116
2,665,333	140	2,667,223	36	2,669,710	16, 316
2,665,384	236	2,667,305	16	2,669,711	316
2,665,385[a]	304	2,667,531[a]	360, 40	2,669,786	16
2,665,386[a]	304	2,667,582	236	2,669,872[a]	148
2,665,409	188	2,667,583[a]	304	2,669,873	148
2,665,416	316	2,667,586	308	2,669,874	148
2,665,420	316	2,667,625[a]	360	2,669,875	200
Re. 23,769[a]	232	2,667,626[a]	516	2,669,877	288
2,665,481	16, 444	2,667,634	316	2,669,928	48
2,665,499[a]	444	2,667,635	316	2,670,134	68
2,665,581	76, 484	2,667,705	16, 216	2,670,179	84
2,665,584	288	2,667,780	140, 12	2,670,441	308
2,665,607	16, 316	2,667,786	288	2,670,442[a]	304
2,665,861	16	2,667,812[a]	324, 368	2,670,446	484
2,665,885	80	2,668,037	80	2,670,454	312
2,665,896[a]	4	2,668,059	224	2,670,547[a]	520
2,665,964	324	2,668,241	236	2,670,625	412
2,665,965	324	2,668,242	236	2,670,649	168
2,666,142[a]	304	2,668,243	168, 196	2,670,660	160
2,666,146[a]	304	2,668,260	236	2,670,926[a]	360, 40
2,666,147	416	2,668,282[a]	360, 388	2,671,034	224
2,666,157	308	2,668,286	316	2,671,154	196
2,666,190	108	2,668,287	312	2,671,174	148
2,666,191	108	2,668,288	316	2,671,178	484
2,666,192	108	2,668,358	200	2,671,197	228
2,666,199	316	2,668,437[a]	88	2,671,198	380
2,666,200	484	2,668,441	496	2,671,202	492
2,666,268	216	2,668,442	496	2,671,203	288, 484
2,666,325	12	2,668,444	428	2,671,206	484, 436
2,666,326	12	2,668,471	168, 416	2,671,275[a]	232, 216

* A key to the subject classification system will be found in GEOPHYSICS, v. 12., p. 256–264 (April, 1947).

[a] Abstracted on preceding pages of this issue.

Patent No.	*Subject*	*Patent No.*	*Subject*	*Patent No.*	*Subject*
2,671,323[a]	520	2,672,050[a]	520	2,672,814	48
2,671,336	168	2,672,054	16	2,672,944[a]	360, 348
2,671,337	168	2,672,155	200	2,672,945	484, 436
2,671,346[a]	100	2,672,195	48	2,673,030	68
2,671,375	360	2,672,204[a]	360	2,673,031[a]	68
2,671,376	416	2,672,283	68	2,673,040	224
2,671,388	444, 16	2,672,284	68	2,673,136	324
2,671,607	68	2,672,285	68	2,673,138	324
2,671,608	68	2,672,312	180	2,673,248	224
2,671,609	68	2,672,334	4	2,673,249	224
2,671,610	68	2,672,392	12, 140	2,673,250	484
2,671,611	68	2,672,394	324	2,673,297	168, 196
2,671,619	224	2,672,395	324	2,673,298	168, 196
2,671,621	16, 312	2,672,512	12	2,673,299[a]	304
2,671,642	80	2,672,559	236	2,673,339	168
2,671,710	324	2,672,560	236	2,673,464	428
2,671,817	308	2,672,561	308	2,673,465	460
2,671,862	484	2,672,602	148	2,673,466	460
2,671,868	308	2,672,608	316	2,673,613	140
2,671,895	312	2,672,609	316	2,673,740	224
2,671,897	312	Re. 23,807	68	2,673,896	224
2,672,047	496	2,672,753	140, 12	2,673,899[a]	372
2,672,048	428	2,672,757	200	2,673,929	68
2,672,049	440	2,672,813[a]	136	2,673,934	308

REVIEWS

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The Earth. Its Origin, History, and Physical Constitution, 3rd Edition, by Harold Jeffreys, New York: Cambridge University Press, 1952. 392 pp. & plates. $13.50.

Harold Jeffreys needs no introduction to readers of this journal. As one of the outstanding theorists of geophysics his prolific studies have touched on almost every phase of the subject, as well as on astronomy and applied mathematics. *The Earth*, one of his best known works, is now in its third edition, after a lapse of twenty three years. Originally the outgrowth of a series of lectures at Cambridge University, the volume has been expanded to include the mathematical arguments necessary for proper exposition of some of the main theories of the earth's interior.

Much of the third edition has been rewritten to take account of the advances made in geophysics since 1929. The four chapters on the origin of the solar system are omitted and the space utilized to extend the remaining chapters. That so much material could be included in a volume of this size is a feat truly remarkable.

Jeffreys' work is essentially that of a theorist drawing on experimental results from many different fields. Through careful selection and evaluation of data he has had better success than others in avoiding a possible pitfall of such an approach, namely, that of prematurely erecting comprehensive theories on weak, uncertain experimental results. It is surprising how much of the second edition remains valid today so far as basic earth structure is concerned.

Only the mathematically sophisticated will obtain full value from this book. However, it is an essential volume for all those interested in a systematic approach to the internal constitution of the earth based on seismology, geodesy, tidal theory, radioactive dating, and astronomy.

FRANK PRESS
Lamont Geological Observatory
Columbia University

Morphological Analysis of Landforms, by Walther Penck. Translation by Hella Czech and Katharine C. Boswell, St. Martin's Press Inc., New York, 1953.

Walther Penck (1888–1923) proposed a system of geomorphology, the goal of which was an understanding of the earth's crustal movements through the analysis of landforms and slopes. He envisioned geomorphology and tectonic studies as supplementing each other in an attempt to find causes of the deformation of the earth's crust. Penck considered landforms as the result of the interaction between destructive processes on the earth's surface and internal forces which uplift parts of the earth's crust; inasmuch as landforms and external processes are subject to direct observation, he believed that from them the nature of the tectonic forces could be deduced.

Penck's system conflicts with the approach to geomorphology developed in America by William Morris Davis. Davis' evolutionary system of the Cycle of Erosion aims at an explanatory description of landforms in terms of the "Geomorphic Trinity" of structure, process, and stage. The controversy between the exponents of these two systems is recorded in the geologic literature from 1924 to the present. Penck's geomorphic system has not replaced that of Davis and many of its tenets are considered doubtful. Nevertheless, there are instances in which erosion surfaces have provided information concerning the nature of uplift and deformation whether interpretation of the origin of the surfaces is in accord with Penck's views or not. Thus, his views point up an application of geomorphology beyond explanation and classification of landforms and serve to give geomorphic study a broader scope.

This translation of Penck's *Die Morphologische Analyse* by Czech and Boswell represents the completion of a project which will be welcomed by English-speaking geomorphologists. Although the original was published in German thirty years ago, the translation still fills a definite need because of the abstruse style and terminology of Penck. This will be readily appreciated even by those who read only the English translation. The translators have kept close to the original wording. Whether this is a strength or weakness is open to question. Perhaps it was wisest in view of the controversial nature of some of Penck's concepts, but it does not make the book as readable as it might be. Any attempt at a synoptic translation runs the risk, however, of altering the meaning of the original statement of Penck's concepts. Short summaries are, however, provided near the end of the book for each chapter, and these should be of considerable value to the general reader.

It is difficult to evaluate the book's usefulness to geologists and geophysicists in petroleum exploration. Certainly the book seems to contain no immediate practical applications to the search for oil, but the work might well be of value in that it suggests a somewhat different approach to the use of landforms which could aid in the solution of some of the broader long-term problems of the earth's deformation.

BRAINERD MEARS, JR.
University of Wyoming
Laramie, Wyoming

"The Transmission of Rayleigh Waves Across Eurasia," by Robert Stoneley, *Bull. Seis. Soc. Am.*, Vol. 43, no. 2, 1953, p. 127–136.

Professor Stoneley's paper deserves the attention of all theoretical seismologists, including those primarily interested in the exploration aspect of seismology. Most workers in this field are painfully aware of the fact that the computation of dispersion curves of surface waves in a system of horizontal

layers becomes very cumbersome when more than one solid layer covering a semi-infinite substratum is considered. Even this single-layer case is quite complicated. Yet it is often desirable to compare empirical data with those calculated for a hypothetical configuration. In the present paper, the hypothetical case consists of two solid layers resting on a semi-infinite medium. In order to avoid the rigorous computation of the dispersion curve, Stoneley resorts to an approximate method, based on Rayleigh's principle. With this principle, an estimate can be made of the modes of vibration of a system by assuming a certain type of motion and equating the mean kinetic and potential energies calculated on this basis. The adaptation of the principle to the layer problem is due to Jeffreys.

In Jeffreys' article it was shown that equations equivalent to the equations of motion and to the boundary conditions of continuity of the stress could be obtained in the form of the conditions under which the integral, with respect to the depth Z, of the difference of the mean potential and kinetic energy densities is stationary. In this integral, the energy densities are expressed in terms of the quantities U and W, which are those factors in the expressions for the components of the particle velocity which depend on Z. By assuming for U and W continuous functions of Z which satisfy the equations of motion with an inaccurate value of the phase velocity, Jeffreys converts his integral to a particularly simple form, but violates the boundary conditions. In the simple form just mentioned, terms occur which can be interpreted as the constraints which must be applied at the boundaries of each layer in order to maintain the assumed motion. The constraints do work, and this work is made a minimum when the mean kinetic and potential energies, calculated from the assumed motion, are equal.

Stoneley's assumed motion is that which can exist as Rayleigh waves in a homogeneous semi-infinite solid. As a further simplification, Poisson's ratio is taken to be one-fourth. The calculation of the approximate value of the phase velocity of the lowest mode is thus reduced to a simple procedure. But how accurate is this approximation?

Some guidance is obtained from Jeffreys' results for a single solid layer on top of an elastic substratum. For this case, both the rigorous and the approximate solutions are available. It is in the nature of the approximation that the approximate velocity is always larger than the velocity of the lowest mode. Although in this example the approximate phase velocity never exceeds the rigorously computed velocity by more than six percent, the error in estimating the thickness of the solid layer is considerably larger and may exceed twenty percent, depending on which part of the group velocity is used for fitting.

Stoneley argues that the error will tend to be less in his case because the changes in the properties of the medium are distributed over more interfaces. Taking into account the errors and uncertainties of the determination of the group velocity from empirical data, he judges that the thicknesses will be overestimated by something like ten percent.

The great advantage of the approximate method is that curves can be obtained for a large number of cases without excessive computational effort. Though there is some doubt about the magnitude of the errors we may be able to get an idea of how the phase velocity is affected by changes in the properties and the geometry of the medium.

Stoneley states that there is "scope for further investigations along these lines." These developments will be awaited with much interest.

G. W. Postma
Shell Development Company
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Houston, Texas

"Crustal Structure and Surface Wave Dispersion, Part III: Theoretical Dispersion Curves for Suboceanic Rayleigh Waves," by W. S. Jardetsky and F. Press, *Bull. Seis. Soc. Am.*, Vol. 43, No. 2, 1953, p. 137–145.

In this paper hypothetical dispersion curves are compared to observed group velocity values. The observations referred to were made on an earthquake in the Solomon Islands, which provided an

oceanic path nearly all the way from epicenter to seismograph. Earlier work had shown that the Rayleigh wave dispersion could be explained satisfactorily by assuming a single fluid layer over a semi-infinite substratum. Observations on Love waves called for the existence of an intermediate layer. The question to be solved was whether the observed Rayleigh wave dispersion would be com patible with the existence of an intermediate layer between the ocean (including sediments) and a deeper substratum.

The results of the computation of three cases are shown, both graphically and numerically. One of these cases refers to a single liquid layer, the two others to two layers, one fluid, one solid, on top of the basement. The latter two differ in the choice of the body wave velocities of the intermediate layer. For all cases Poisson's ratio of the solid materials is 1/4. The authors conclude that it may be possible to distinguish between these two cases, but only when the thickness of the intermediate layer is at least of the order of the ocean depth. The two-layer case which is in best agreement with available data from refraction work in the Pacific leads practically to the same dispersion curve for Rayleigh waves as the one-layer case.

In view of the work involved in the numerical solution of the period equation, the derivation of which is in itself quite a feat of algebraic manipulation, it is not practical to test the significance of the parameters determined from Rayleigh observations by computing a sufficiently large number of cases. One must be satisfied with the demonstration that reasonable assumptions about the layers lead to agreement with observations, but the reader might speculate that the insensitivity of the dispersion curve for at least some of the parameters might account for the good agreement between theory and observation. This reviewer agrees with the authors that studies are desirable on the influence on the dispersion curves of variations of water depth and of refraction at the continental border.

G. W. Postma
Shell Development Company
Exploration and Production Research Laboratory

"Direction of Approach of Rayleigh Waves and Related Problems (Part I)," by Jack Foord Evernden, *Bull. Seis. Soc. Am.*, Vol. 43, Oct. 1953, p. 335–374.

Convincing arguments and evidence are presented against the explanation of the coda in earthquakes in terms of natural vibrations of the earth's crust either at the source or at the observation station. For an explanation of these later phases of seismograms the author looks rather toward multiple reflections in the layered crust and the overlying oceans.

It is shown also that Rayleigh waves do not only reach the seismic station along the great circle passing through the source, but that different phases of Rayleigh waves travel along different paths and approach the observation station from different angles, thus leading to a wandering of the plane of polarization. Observations on a single station thus might suggest a spurious transverse component of the Rayleigh wave. The author has verified that no such transverse component exists when the direction of propagation of the Rayleigh waves is properly determined using the tripartite method.

A. S. Ginzbarg
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Exploration and Production Research Laboratory

"Earth Tides," by J. T. Pettit, L. B. Slichter, and L. LaCoste, *Trans. Am. Geophysical Union*, Vol. 34, no. 2, April, 1953, p. 174–184.

This paper reports on the analysis of a long series of tidal gravity observations made at Los Angeles, Pasadena, Hawaii, and Attu. The measurements appear to be of substantially higher quality and precision than those of any previous published similar work. (See, for instance, a review of three papers in Geophysics, Vol. 17, no. 1, January 1952, p. 148.) The method of analysis is also different and leads to much more definite and constant values for certain parameters.

The new feature is that the analysis is carried out on the difference between the calculated theoretical tidal gravity for a rigid earth and the observed gravity variations. This difference has a maximum amplitude of the order of 80 microgals (80×10^{-6} gal). It is found that this difference can be represented quite closely by an amplitude factor by which the theoretical gravity is multiplied and a phase lag. Furthermore, it is found that the amplitude factor and phase lag are constant at a given location but vary considerably from one location to another. The observations at Los Angeles and Pasadena were best represented by amplitude factors of .35 and .32 respectively and at both stations the phase lag was 80 minutes. At Hawaii the amplitude factor is .53 and the phase lag 180 minutes. These phase lags are much larger than those which have been obtained from other analyses of similar observations. This is because the analysis is applied to the component of the gravity disturbance due to the tidal deformation of the earth rather than to the entire disturbance. If, as seems to be indicated, the amplitude and phase factor are constant at a given location (and possibly over a considerable area), it would be possible to calculate actual tidal gravity from the formulas for the rigid earth plus the component for the local tidal deformation. This should give greater accuracy than can be obtained by the generally used methods of increasing the theoretical value by a rather arbitrary factor of around 20%. However, it would require a much higher degree of precision and stability in gravity meters before the increased precision could be an appreciable factor in gravity observations.

L. L. NETTLETON
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Houston, Texas

"Simple Apparatus For the Determination of The Magnetic Susceptibility of Rocks," by K. Sebestyen, *Geofizikai Kozlemenyek*, II, 2.

"Computation of Anticlinal Datas from Refractional Travel-Time Curves," by J. Kilczer, *Geofizikai Kozlemenyek*, II, 3.

Reprints of these two articles were received, the articles having been published in a relatively new Hungarian geophysical journal. The articles are written in Hungarian and no attempt has been made to evaluate their content. The authors' abstracts are respectively as follows:

"The author described a simple apparatus by which the magnetic susceptibility of rocks can be determined with great accuracy even under field conditions. The principle of the apparatus is based upon the fact that the natural frequency of an oscillating circuit will change if, instead of air, the material under investigation will be inserted into its induction coil. The reduction of the size of the apparatus has been made possible by applying a flashing quartz crystal as frequency norm."

"This work gives a computation method for the determination of anticlinal datas (dip, depth) appearing in the refractional travel-time curves with an exactitude permitted by the precision of the observation data."

NELSON C. STEENLAND

"Geologic Controls of Lead and Zinc in the Good Springs (Yellow Pines) District, Nevada," by C. C. Albritton, Jr. et al., and Structural and Igneous Geology of the La Sal Mountains, Utah," by Charles B. Hunt, *Science*, Vol. 119, no. 3093, April 9, 1954, p. 474 and p. 477, respectively.

These two brief articles list and discuss facts observed on specific mineral deposits. The practicing mining geophysicist might well acquaint himself with the geologic details of mineralization such as are discussed here.

The lead and zinc mineralization in the Yellow Pine District of Nevada occurs in complexly faulted thrust sheets. The varying degrees of strength of the sedimentary formations in the thrust sheets affect the amount and pattern of fracturing in the sheets and, in turn, control the mineralizing. The Monte Christo limestone is a comparatively strong unit of massive rock between thinly bedded formations. The limestone responded to deformation by fracturing instead of by flowage and appar-

ently the "mineralizing solutions rose along conduits opened by intersection of faults and joints or by differential movement along arcuate faults."

The La Sal Mountains of Utah have for the past several years been considered to be the source of the uranium mineralizing solutions of the Colorado Plateau and adjacent areas. The exact nature of the role of the La Sal laccoliths in the mineralizing processes was not, however, studied in detail. Therefore, the U. S. Geological Survey undertook to study the basic considerations involved. The earliest intrusions are indicated to be diorite porphyry, followed by monzonite porphyry followed by syenitic rocks. "The radon is least in the dioritic intrusion and greatest in the syenitic ones." All of the radioactivity in the intrusive rocks is apparently related to the magmatic differentiation and not to hydrothermal activities.

NELSON C. STEENLAND

"Total-Intensity Magnetic Anomalies of Three-Dimensional Distributions by Means of Experimentally Derived Double Layer Model Fields," by Isidore Zietz & Roland Henderson, *Science*, Vol. 119, no. 3088, March 1954, p. 329.

The reviewer, Mr. Zietz, and Mr. Henderson collaborated with Mr. Victor Vacquier in the writing of the GSA Memoir 47, "Interpretation of Aeromagnetic Maps." That volume contained many maps of the magnetic fields of models. The immense effort in calculating the fields of these models together with the inaccuracies inherent in the graphical integration process made a strong impression on the authors and lead to continuing effort on the part of Zietz and Henderson to measure the fields of models with a magnetometer instead of undergoing laborious calculations.

This is the first report on their progress. Their models consisted of slabs constructed of one part powdered magnetite and two parts plaster of paris, 0.5 in. thick, with horizontal dimensions 5×20 5×30, 5×5, 10×30, 10×10, 20×20, 2½×20 and 10×20 inches. Their fields were mapped with a detector below the model which could be translated in either a north-south or east-west direction. The detector used was a second harmonic flux-gate type magnetometer which recorded continuous profiles.

The authors plan to make these field maps available with dimensions that are "independent of the susceptibility of the model and the strength of the inducing field, and dependent only on the geometry of the prism." In this way complicated blocks may be constructed by combining the prismatic blocks. The desired values of susceptibility and inducing field strength may be introduced.

NELSON C. STEENLAND

"Annual Review, Geophysics," by Kenneth L. Cook, *Mining Engineering*, February, 1954, p. 184–189.

Mr. Cook, a former member of this committee, reviews the activities in mining geophysics throughout the world during 1953. His article is of extreme interest because mining geophysics made an unusually great stride forward during the past year.

This is quite evident in the allocation of expenditures for geophysical exploration by large companies. A distinct increase in the use of magnetic, gravity, radioactive and geochemical methods is apparent.

Magnetic surveys are credited with high-grade iron discoveries in Nevada and in southern California. Three electromagnetic anomalies in New Brunswick, Canada, disclosed very important lead-zinc sulphide deposits in the Bathhurst area. Apparently the electromagnetic surveys followed the discoveries of significant aeromagnetic anomalies. The magnetometer found a large magnetite ore body near Mamora, Ontario. The original anomaly was discovered on airborne maps made by the Geological Survey of Canada, indicating that in Canada the quality of government geophysical surveys is sufficient to compete effectively with commercial exploration.

The discussion of geophysical mining efforts in Europe and in the Near East does not indicate a state of aggressiveness comparable to that in the United States.

Again we have to go to one of the English speaking countries, Australia, to find a government effectively assisting in the search for radioactive minerals. Fifty separate uranium discoveries resulted from indications by airborne reconnaissance. In addition, the government is sponsoring geochemical exploration, and two lead deposits were discovered by the analysis of residual soil.

NELSON C. STEENLAND

PUBLICATIONS RECEIVED

American Journal of Science, v. 252, nos. 2, 3, & 4 (Feb., Mar., & April, 1954)
Annali di Geofisica, v. 6, no. 3 (July, 1953)
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DISCUSSIONS AND COMMUNICATIONS

LETTERS TO THE EDITOR

MICROSEISMS IN SCANDINAVIA

To the Editor of GEOPHYSICS

Uppsala, March 24, 1954

In the October, 1952, issue of GEOPHYSICS, Dr. William Donn was kind enough to review three of my papers concerning microseisms. Unfortunately this review has not come to my attention until now. As it contains a few misleading statements I will comment on them.

I have not found a period of 28 years but slight indication of a 28 months' variation.

The statement that "the effective sea wave energy (in dimensionless units) is 37×10^{-7}" is just nonsense. It should read that the part of the sea wave energy which is transformed into microseismic energy is 37×10^{-7}, and as the ratio between two energies this number is dimensionless.

Concerning the direction determinations by means of Lee's and Bungers' methods Donn says that cyclonic storms over the North Atlantic would give similar azimuths. This is certainly true and has been pointed out by me, but the fact is that there were no cyclonic storms over the North Atlantic for the cases where direction determinations were made. In both cases the cyclone was situated north of Russia, i.e. approximately NE of Uppsala, and it was considered of importance that the directions did not point to the center of the cyclone but in a NW direction. And as pointed out by me, this taken by itself does not prove any coastal effect, although it does not contradict it. But there are a number of other kinds of evidence which definitely prove the existence of a coastal effect in our area. For further discussion I will refer to a coming paper "Review over Investigations of Microseisms in Scandinavia."

Donn remarks on the limited extent of the weather maps I used. For reasons of space, only these limited charts were published, but when the studies were made I had at my disposal weather maps covering the whole area of the North Atlantic. A supposed explanation of the time lag by Donn has therefore no meaning. This is also evident from another paper which will soon be published ("The Microseismic Time Lag Problem").

Donn believes that the microseisms originate from direct effects of turbulence whereas the sea waves should be of no importance. This is a point where I think one has to be careful. In a recent study I have made ("Comparison of Microseisms in Greenland, Iceland, and Scandinavia," *Tellus*, Vol. 5, No. 2, pp. 109–134, 1953) I found that the conditions for microseism generation are quite different even within the relatively limited area mentioned. Concerning microseisms we must always keep in mind that what has been found in one place may not be true in another place. Differences between east and west coasts seem to be essential, not to mention other reasons for differences found.

Concerning the study of 18 cases in connection with the microseismic importance of cold fronts Donn says that the 18 individual cases "support most other observations that microseisms decrease when fronts or cyclones are over land." This is not what I have said and it is also a completely wrong statement. Just the opposite is true, which is also shown by the study mentioned.

Dr. Donn and anybody else, especially those who doubt our results, are cordially invited to study our records. It seems impossible to me to have definite opinions about Scandinavian microseisms only from experience of what happens on the east coast of North America. Recent studies of microseisms conducted in Bergen and in Hamburg, and also a minor investigation in Copenhagen, have all confirmed the results I have earlier obtained.

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Meteorological Institute
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SEG DEPOSITORY AT THE UNIVERSITY OF TULSA

The University of Tulsa
Tulsa 4, Oklahoma
April 5, 1954

To the Editor of GEOPHYSICS:

In accordance with a suggestion made by Mr. Colin Campbell, we are reporting on the library of the Society of Exploration Geophysicists.

This collection, which has been in the University of Tulsa Library since 1947, comprises 133 serial publications and 33 books and monographs, as well as a large number of reprints and extracts. Important geological and geophysical publications from throughout the world, including some of the Iron Curtain countries, have been received by the Society and placed in the library. Unfortunately, many of the serial titles are represented by only a few issues, frequently only one or two. There are no complete files of any journal, and there are in many instances issues missing from the volumes found in the SEG holdings.

Although comparatively few local members of the SEG have made use of the depository, many out-of-town members have borrowed material by mail and some have visited our library to use the collection. Approximately two items a month have been mailed to members. With one exception, items borrowed have been returned promptly and in good condition. One shipment containing two journals apparently went astray in the mails while being returned from Pittsburgh, Pennsylvania during August of 1953.

One SEG member, Dr. Harold Mooney, at his request was placed on our mailing list to receive regularly seven publications in which he is particularly interested. This arrangement has worked out very satisfactorily, I believe.

Limited use of the collection has been made by members of the student body and faculty of the University of Tulsa. If files were complete, they would probably be used much more frequently by members of the university community.

It is interesting to note that the two publications most frequently requested by society members are in the Russian language. They are Dakhnov's *Electric Well Logging* and Alpin's *Theory of Electrical Well Logging*.

Our suggestions for increasing the usefulness of the SEG Library are as follows:

1. Reviewers should send all publications to the library as promptly as possible.
2. An effort should be made to complete files of important journals.
3. If possible, complete volumes should be bound.
4. Complete files of geophysical journals on microcards should be added to the collection.

Since we value the SEG Library highly, we hope that you will not consider our suggestions for improvement as criticism. We are very grateful to the Society for having selected our library as the repository for its collection and we sincerely hope that the members are entirely satisfied with our administration of it. We are particularly grateful to Mr. Colin Campbell who has been unfailingly helpful and gracious when we have frequently had to turn to him for advice.

EUGENIA MADDOX
Librarian

NOTES ON FRASER S. GRANT'S PAPER: "A THEORY FOR THE REGIONAL CORRECTION OF POTENTIAL FIELD DATA"

April 6, 1954

To the Editor of GEOPHYSICS:

In an eloquent paper Grant (1954) has commented briefly on my paper, "Regional Correction of Gravity Data" (Vajk, 1951), stating that I argue in favor of graphical methods in determining a regional gravity effect and objected strongly to my conclusions that

". . . the regional effect cannot be determined uniquely. It is an interpretation problem which cannot

be solved by some mechanical mathematical methods but only by analysis of the gravity data. Such determination is unavoidably a subject of personal factors as is every gravity (or magnetic) interpretation."

As Grant's criticism propagates the idea that by analytical methods "the" regional effect can be determined unambiguously and objectively without being influenced by "personal judgements and prejudices," I take the liberty to elucidate a few points.

I did not "argue" in favor of graphical methods for the determination of the regional gravity, but in favor of the analysis of the gravity data. It is true, I prefer graphical methods to the mathematical approach because they furnish a simple way for a relatively quick solution. Yet it is obvious that the recommended process—to find a curve which fits the smooth parts of the gravity curve (allowing a vertical shifting of some parts)—can be solved mathematically as well as graphically. The question it is not *how* we do it, but rather *what* we do.

The analytical method Grant presented in his paper is based on the assumption that the smoothed gravity curve is the regional effect, which is, of course, completely arbitrary. It is a "personal judgement." This assumption being identical with the basic idea of the graphical smoothing, Grant's method has all the fallacies of the smoothing method which I discussed in my paper (Vajk, 1951). I may repeat: *what we do* is essential; how we do it is another matter.

The crucial point of the whole problem lies, of course, in the ambiguity of the gravity interpretation. This ambiguity is twofold. The *first aspect* of the ambiguity lies in the fact that every gravity effect may be due to any number of separate masses, or "structures." It is just as impossible to separate (without geological information) the actual components of the gravity field as it would be to try to determine those individual numbers the sum of which is a given number when we do not even know how many numbers were added. It is obvious that this cannot be done by any mathematical procedure alone.

The *second aspect* of the ambiguity of gravity interpretation is that, even when the gravity anomaly is due to a single "structure" (density contrast surface), there are an infinite number of structures, the gravity effect of which correspond closely (within the limit of accuracy of the data) to any given gravity anomaly (Barton, 1929; Skeels, 1947; etc.).

If we recognize that an inherent ambiguity is present in the separation of the regional effect, just as it is present in the interpretation of a gravity anomaly due solely to a single structure, then we must accept the fact that a unique determination of the regional gravity effect is impossible no matter how involved a mathematical procedure is used in attempting it.

I would like to discuss the "personal factor" and "prejudice" briefly. The "personal factor" in geophysical interpretation represents, of course, the geological background of the interpreter. It includes all the geological data known by him, all the sound geological theories and assumptions he accepts or develops. Personal prejudice means the preference of the interpreter for one assumption over the other.

It follows that the "personal factor" and "prejudice," as defined above, is not something arbitrary to which one should take objection, but a useful and necessary asset. A purely mathematical interpretation of the gravity data is, at best, only one of the infinite number of *possible* solutions. The "personal factor" advances a *possible* solution into a *probable* solution.

Finally, I wish to quote from van Weelden's excellent paper (van Weelden, 1953):

"I advocate strongly to forget about the objectionable features of 'personal equation' and bias. I believe that a graphical system whereby we can be guided by our geological knowledge is far preferable over the mathematical approach.

"The gravity method like all geophysical ones is one tool in the arsenal of the prospector. To ignore this and try to use it as a purely physical or mathematical method means diverting it from its purpose and reducing it to a toy for abstract mathematicians. No cleverly thought-up slogan about 'personal equation' can alter this."

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New York, N. Y.

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PRIZE-WINNING ESSAY
OF
FIRST ANNUAL STUDENT ESSAY CONTEST IN GEOPHYSICS SPONSORED BY SOCIETY OF EXPLORATION GEOPHYSICISTS

THE WILLISTON BASIN AND ITS EXPLORATION PROBLEMS*

GERHARD E. LUKK†

Only recently has the Williston Basin, which gets its name from the City of Williston located on the Missouri River 20 miles east of the Montana-North Dakota border, become of great interest to the exploration departments of the oil industry. This interest in one of the largest and oldest geological basins in North-America was created by discoveries of oil in commercial quantities. A minor discovery was made in February, 1951 near Virden, Manitoba, followed by the discovery of the Clarence Iverson Well in the vicinity of the Nesson Anticline on the 4th of April, 1951, followed by the discoveries of September, 1951 in the H. O. Bakken Well in the Tioga pool and in December of the same year the Shell Oil Company's discovery at Richey, Montana. The Virden Well is located near the northeastern border of the Williston Basin and Madison production was developed there by the California Standard Company. The Clarence Iverson Well was developed by the Amerada Petroleum Corporation and it produced from the Devonian and Madison.

Since those discoveries numerous other discoveries of oil in commercial quantities have been made in Montana from the Madison and Devonian and in southern Saskatchewan from the lower Cretaceous. The pace of discoveries kept increasing steadily throughout 1952 and 1953 as many new discoveries were made in southern Saskatchewan, northern Dakota, and northeastern Montana.

It is interesting to note that prior to the discovery of oil in commercial quantities within the area encompassed by the Williston Basin several attempts dating back as far as 1907 were made to discover oil in this region. There were several strikes of oil in 1935 on the Cedar Creek Anticline but they recovered only relatively small amounts of oil and hence were not of much interest at that time.

At present it is very hard to define the exact boundaries of the Williston Basin and to discuss its complete structure as there is much data available, a great deal of which is conflicting in nature.

The Williston Basin as it is known at present extends over southern and southeastern Saskatchewan, southwestern Manitoba, western North Dakota, northwestern South Dakota, and northeastern Montana. Whether the Williston Basin extends into southeastern Alberta is still debated. On the whole the Williston Basin covers an area of some 130,000 square miles.

The Williston Basin can be regarded as being bounded by the following structures: the pre-Cambrian Canadian Shield in Saskatchewan, Manitoba, and its extension into Minnesota; the Sioux Uplift in southeastern South Dakota; the Sweetgrass Arch; the Bowdoin Dome, and the minor Porcupine Dome in Central Montana. The Black Hills Uplift separates the Williston Basin from the Rocky Mountain tectonic features and in northwestern Saskatchewan the Williston Basin merges into the Moose Jaw Syncline. (The generally accepted outer limits of the Williston Basin at present are shown in Figure 1.)

On the surface the structure of the Williston Basin is rather simple. The subsurface structure of the Basin, however, becomes consistently more complex with the new information that is made available with its exploration.

It has been established that the Williston Basin has been downsinking during most of the Paleozoic and subsequent times. The pronounced basining is thought to have started in post-Ordovician or post-Silurian time. In the Devonian, Mississippian, and Cretaceous time the downsinking nature of this particular area is most pronounced. It is interesting to note that the center of the Basin has not

* This entry won the only prize ($150) awarded by the SEG for the best student essay submitted in its first annual contest. Presentation of the prize was made by F. J. Agnich, Chairman of the Student Essay Contest Committee, at the St. Louis Meeting.

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been fixed during the downsinking of the Basin, but has been changing its location as indicated in Figure 1.

Several anticlines, such as the Nesson, Cedar Creek, and Poplar Anticlines and synclines, such as the Moose Jaw, Blood Creek, Sheep Mountain, and Lemmon Synclines are known to be present within the Williston Basin. The origin of these structures is of some interest as there are several ways in which they could have been produced. Some of these east-west and northeast-southwest folds may be due to pre-Cambrian highs. Folds could have also been due to ice shove, although it seems rather unlikely that disturbances of such great magnitude would have occurred in this area due to such ice movements.

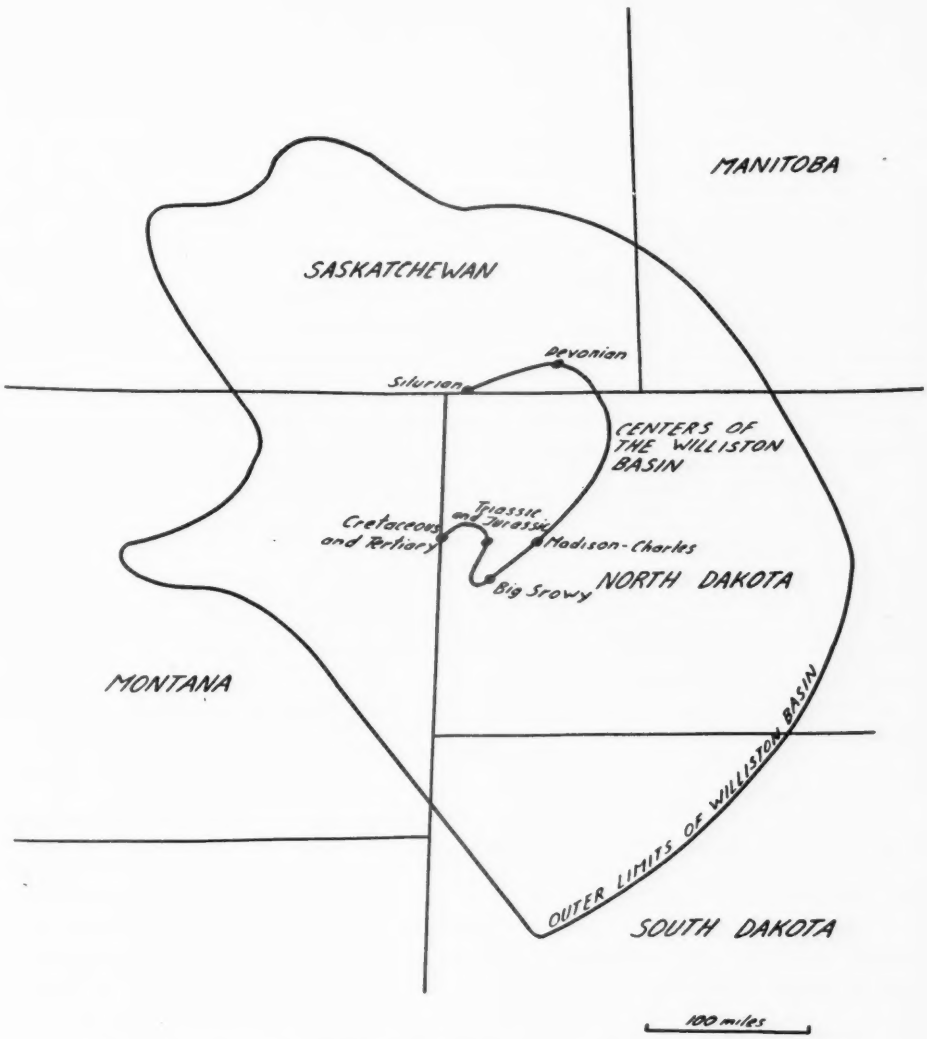


FIG. 1. Outer limits of Williston Basin and migration of the centers of the Basin through geologic time.

The parallelism of most anticlines with the Cedar Creek Anticline would suggest an orogenic fold of some kind. However it is hard to see how these structures could be due to horizontal forces in such incompetent beds as those of the Cretaceous and the overlying Cenozoic beds.

At present two possibilities seem to be regarded as the most likely ones. One possibility on the formation of some anticlines is that as the Basin sank it caused folding of the rocks in the center part of the Basin due to the crowding of the strata in that region of the Basin. The other possibility suggests deep-seated faulting. It is known that the western side of the Cedar Creek Anticline is much steeper than the eastern side. This might be due to faulting at depth, and some geologists suggest that at the northern end of the western side of the Cedar Creek Anticline faulting extends to the surface. Hence we can assume that some of the anticlines in the Williston Basin may be due to deep-seated faulting, probably in the basement rock. It is important to note that if the folds are due to deep-seated, high-angle type faulting then they would not have to be closely aligned. Hence we could have cross folds at angles to the general structural trend of the Cedar Creek Anticline.

Besides the many structural unconformities there are a great number of stratigraphic traps present in the Williston Basin, that are of interest from the point of view of oil exploration. One of the most important stratigraphic unconformities is that at the base of the Triassic-Jurassic beds.

From cross-sections (Fig. 2) it can be seen that the Triassic and the Jurassic overlap beds from the Permian to the Ordovician age and possibly even older beds. Near the part where the Triassic lies directly on top of the Mississippian, a zone of porosity has been developed in the Madison. This porous zone is of importance to oil exploration as it could very well serve as an oil accumulating reservoir. Other stratigraphic structures that are known to be present in the Williston Basin and that are of interest from the point of view of oil accumulation are wedge-outs and reefs. Reefs are known both from the Upper Devonian in Alberta and Montana and from the Middle Devonian in Manitoba. Possible reef structures may be present in the Silurian and Ordovician, although less is known of them.

STRATIGRAPHY

We can divide the unconformities in the Williston Basin into four major parts:

(1) The unconformity at the base of the Paleozoic rocks.
(2) The unconformity at the base of the Devonian.
(3) The unconformity at the base of the Triassic and Jurassic.
(4) The unconformity at the base of the Cretaceous.

There are also a number of pronounced evaporatic sequences in the central part of the Williston Basin. Evaporites are known in practically all of the Paleozoic sequences but they are not prominent until the salt deposition of halite and anhydrite in the Devonian at which time the center of the salt basin was apparently in Saskatchewan.

Sedimentation during the Paleozoic was due to the clastic sediments eroded from the pre-Cambrian land mass to the southeast, east, and northeast of the present Williston Basin.

Cambrian

The Cambrian formation of the Williston Basin consists largely of interbedded green shale and dolomite overlying a basal glauconitic sandstone.

Ordovician

Three Ordovician formations have been found in the Williston Basin. They are, from the base upwards, the Winnipeg formation, the Red River formation, and the Stony Mountain formation. All these formations are thought to be of the Upper Ordovician age. The thickness of the Winnipeg formation is up to 500 feet. This formation consists mostly of green gray shale, sandy limestone, and gray limestone. These sandstones are noted because of their friability and their extensive porosity and permeability. So far though only minor oil shows have been found in the Winnipeg formation.

The Red River formation varies in thickness up to 600 feet and consists mainly of gray to tan,

dense to granular dolomite, and sandy limestone. It has numerous zones of porosity, particularly toward the top of the formation, which have produced oil in commercial quantities.

The thickness of the Stony Mountain formation is as large as 500 feet in places. It consists largely of dolomitic limestone and shale. In Manitoba, on the outcrop, this formation consists mostly of red and green shale and interbedded limestone. Many fossils are also found in the Stony Mountain formation indicating favourable life conditions on the sea floor.

Silurian

The Silurian formation of the Williston Basin has been positively identified only during the past two years. It is rather thin as it is not known to exceed 300 feet in thickness. The Silurian formation is mostly made up of white to pale-coloured lithographic, sugary dolomites, and minor shale beds.

On the outcrop of the Silurian there are suggestions of possible reef conditions, although no large reef masses have been encountered at the surface. Notable reef-like conditions have been encountered for example in the California Standard Company Planche Thompson Well in Bottineau County, North Dakota.

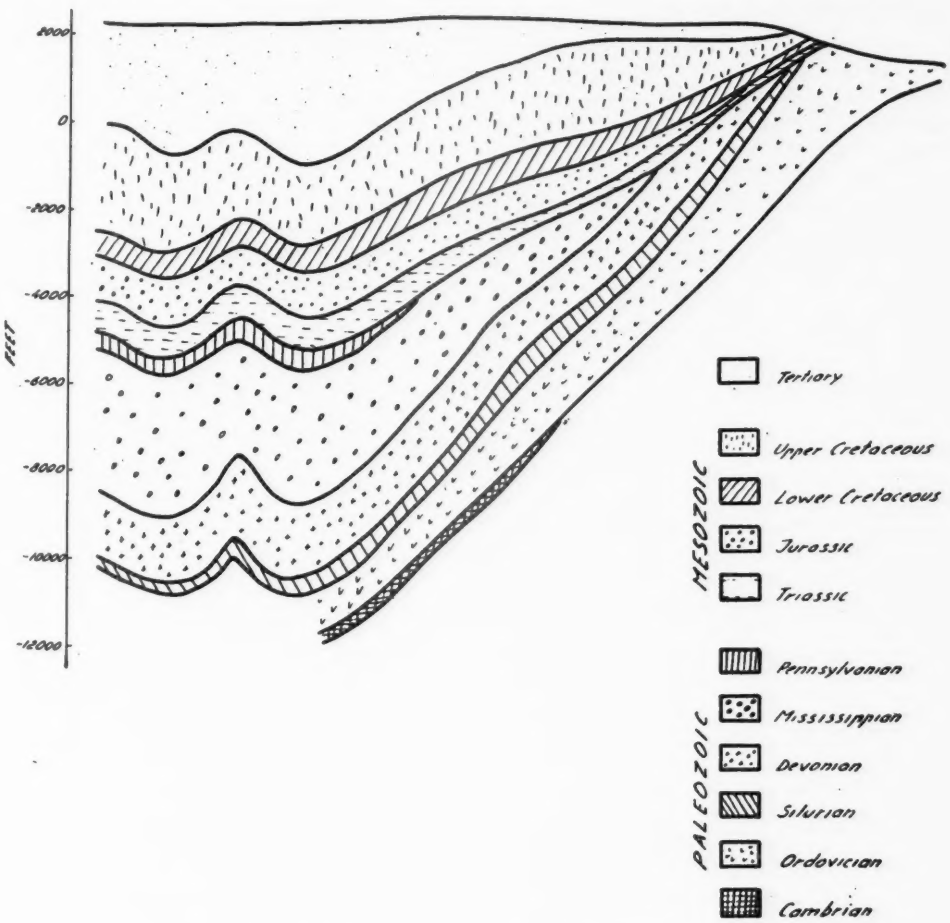


FIG. 2. A typical east-west cross-section of the Williston Basin.

It is interesting to note that the Upper Silurian time and probably all of the lower Devonian time is not represented in the Williston Basin. Hence there must have been an extensive period of non-deposition or erosion.

Devonian

The Devonian formation is one of the most interesting formations if we regard it from the point of view of oil occurrence. It is mainly of such great interest due to its prolific production in Alberta. (In Alberta the producing beds are of Upper Devonian age.)

The Ashern formation is the oldest Devonian deposit known in the Williston Basin. This formation is also known in Saskatchewan under the name of Third Red as it consists of a dolomitic shale and dolomite which is frequently red in colour.

Overlying the Ashern formation are limestone and dolomite beds known in Manitoba as the Elm Point and the Winnipegosis formations.

At the outcrops the Winnipegosis indicates some well developed reef-like features. The Elm Point, the Winnipegosis and its evaporite facies (that become evident towards the central part of the basin), and the Ashern formation make up the Elk Point group.

Following the Elk Point group we have the Beaver Hill Lake group. The Beaver Hill Lake group consists of the Dawson Bay and the Souris River formations. Shelf-like limestones of normal marine to coarsely crystalline carbonate rocks with small amounts of anhyrite and shale make up these formations. An extensive evaporite sequence is developed in the central part of the Beaver Hill Lake group in Saskatchewan, indicating that the evaporatic conditions moved to the north and west in later Devonian time.

Next comes the Saskatchewan group, consisting of the Duperow and the "Nisku" formations. Gray limestone and dolomite make up the main part of the Duperow formation. The "Nisku" formation consists of dark crystalline limestone and anhydrite and has exceptionally large irregular porosity developed in it. This type of structure would be ideal for oil accumulation, although to date no oil has been found in it.

Underlying the "Nisku" and hence separating it from the Duperow is frequently a thin shale bed known as the Ireton. (The Ireton causes a distinct kick on the electric log.)

The final Devonian group is the Qu'Appelle group consisting mostly of a shale and dolomite sequence.

Mississippian

There is hardly any time break, if any, between the Devonian and the Mississippian. The oldest Mississippian formation consists of dark grey to black shale. This formation has been called the Bakken formation, it is also known as the Englewood formation. The Bakken formation is very often well shown on electric logs and gamma ray logs, which makes its identification reasonably easy.

Overlying the Bakken formation, that is Kinderhook in age, is the Madison group. The Madison group consists of three formations: the Lodgepole, the Mission Canyon, and the Charles, the Lodgepole being the oldest and the Charles the youngest formation of the three. All three Madison formations are mostly made up of different types of limestone beds.

The Lodgepole and Mission Canyon beds are of shelf-like limestone deposits. The most interesting formation of the three, from the point of view of oil exploration, is the Mission Canyon. There are several sections in the Mission Canyon which show good porosity and it is the Mission Canyon formation in which the major portion of the oil in North Dakota has been found. The Charles formation, that consists of an evaporatic sequence of massive anhydrite, salt, dolomite and some fossiliferous limestone, has been producing oil in eastern Montana.

The Madison formations are followed by the Big Snowy group. The Big Snowy group consists of (starting from the base upwards) the Kibbey, the Otter, and the Heath formations.

Pennsylvanian

Overlying the Heath is the "Amsden" formation, the exact age of which is not known. It is assumed at present though that the "Amsden" is of Pennsylvanian age. It is possible that the "Amsden" and the Minnelusa of Pennsylvanian age may be rough equivalents and simply be facies phenomena of each other.

Permian

The Permian is poorly represented in the Williston Basin. The two main formations are the Opeche shale formation at the base and the Minnekahta limestone formation at the top.

Triassic

A formation of red shale and sand with some evaporites, known as the Spearfish formation, represents the Triassic in the Williston Basin.

Jurassic

Following the Triassic formations are the Jurassic formations, which are divided into the Ellis group below and the Morrison formation above.

The Ellis group consists of marine and evaporite sequences whereas the Morrison formation is a sequence of continental deposition.

An important feature of the Jurassic is the fact that it is a transgressive sequence, transgressing rocks of all ages from the Triassic down to the Cambrian.

The Ellis group is easily distinguishable by the presence of an oolitic limestone at the top of the Piper formation. This limestone besides being an excellent marker bed has to be considered, due to its porosity, as a likely oil accumulative formation.

In Saskatchewan the Eastend, Gull Lake, Wapella, and Java fields are producing from the Jurassic.

Following the Morrison formation is a great unconformity representing some of the upper Jurassic and almost all of the lower Cretaceous time. This time interval is regarded as one of considerable erosion.

Cretaceous

On the American side of the Williston Basin the basal sequence of the Cretaceous is known as the Cloverly or the Dakota group. This group, which consists of two sand sequences separated by shale, has been productive of oil in the Cat Creek field, Eastern Montana. In North Dakota oil in commercial quantities from these formations has yet to be found, whereas in Saskatchewan considerable amounts of oil and gas have been discovered in the basal portion of the Cretaceous.

The next most important sequences in the Cretaceous are the Greenhorn and the Muddy formations. The Greenhorn formation is of importance as it can be well used for widespread correlation due to its distinct "kick" on the electric log.

The Muddy formation, which is a lenticular sand sequence, is of interest as oil staining has been noted in it.

The lenticular sand and the oil staining implies that we definitely have to regard the Muddy formation as a potential shallow oil horizon.

Tertiary

The early Tertiary time is represented by the Cannon-ball formation, in the eastern part of the Williston Basin, and the continental beds of the Tongue River lignite-bearing formation. The remaining Tertiary time is only poorly represented in the Williston Basin.

The advance of the glaciers is the last important event of a geological nature that affected the

Williston Basin. The glaciers brought with them huge amounts of materials which were widespread in the northern and eastern parts of the Williston Basin. This geologic event is of great interest to oil exploration as it hampers considerably seismograph operations and surface geologic work.

SEISMIC PROBLEMS

The main difficulties encountered in exploring the Williston Basin, using seismic methods, will now be discussed. (A typical east-west cross-section of the Williston Basin is shown in Figure 2).

First let us consider the possible correlation of Mesozoic structures, e.g. folds found by seismic work, to the underlying Paleozoic beds. It is known that in the Williston Basin the Paleozoic era was followed by an extensive erosional period. Hence the Triassic, as can be seen from Figure 2, covers beds from the Pennsylvanian down to the Ordovician. It is only too natural to assume that the contact between the Triassic and the Paleozoic beds is not a smooth surface because of the variable resistance to erosion of the different Paleozoic beds and the change of the magnitude and type of erosional forces during the exposure of the different sedimentary layers. To which extent the topography of the Paleozoic is reflected into the overlying Mesozoic is dependent on many factors, one of the most important ones being the differential compaction of sands, shales, and limestones. Unfortunately very little is understood about these differential compactions and hence it is difficult to correlate sections of Mesozoic beds with sections of the underlying Paleozoic formations.

It is important to note that the velocity anomalies associated with the irregular Paleozoic topography will distort the reflection times from any Paleozoic bed.

From outcrops in the vicinity of Winnipeg and information obtained from various wells drilled it is known that in the Williston Basin reefs are present in the Middle Devonian and Silurian. The ability to locate reefs, as they are one of the most important structures in oil exploration, is always one of the major problems. In the North Dakota portion of the Williston Basin the Middle Devonian

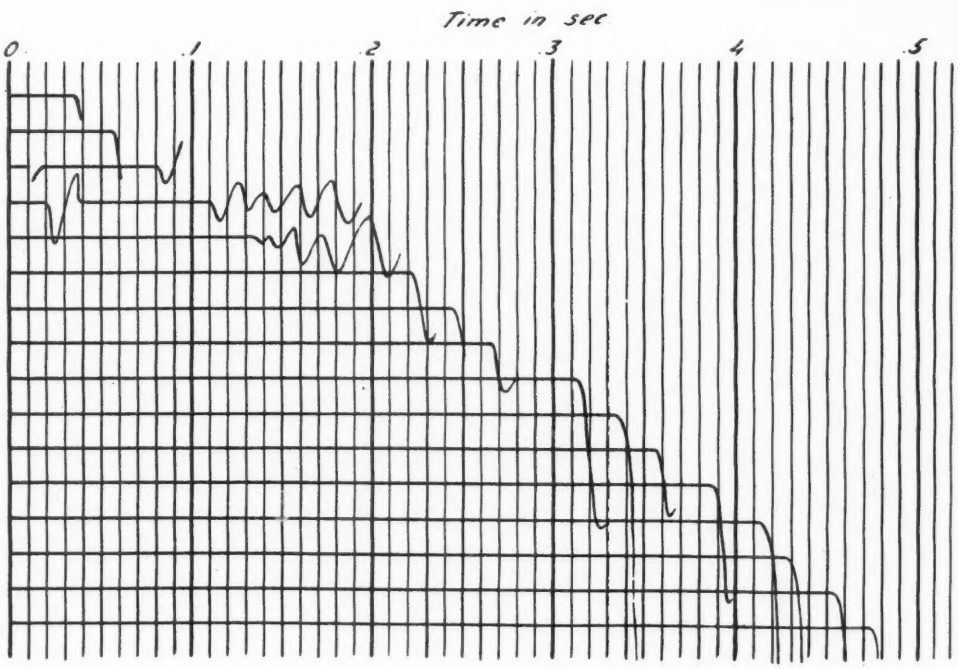


FIG. 3. First breaks of a typical Williston Basin seismic record.

and Silurian are composed mainly of limestones and dolomites and it is the belief of various geologists that reefs which are present in limestone sections will cause only a small amount of structural distortion of the formation above. Hence the velocity anomalies caused by the structural distortions produced by the reefs will be small and consequently it is difficult to locate the reefs.

The Devonian and Silurian in the Saskatchewan part of the Williston Basin differ considerably from the corresponding beds in North Dakota. In the Saskatchewan part of the Williston Basin thick deposits of rapidly varying thickness of evaporites were laid down during the Devonian and Silurian. Although the distortion produced due to the Devonian and Silurian reefs in Saskatchewan has been found to extend into Mesozoic formations, it is difficult to recognize these distortions as being due to reef formations.

As the salt beds of the Middle Devonian and Silurian constitute one of the largest known evaporite basins, we may not overlook the possibility of flow of this huge salt mass causing possible structures in the Upper Paleozoic that would also be reflected into the overlying Mesozoic beds.

Vertical velocity variations in the near-surface formations of the Williston Basin are also of prime importance in seismic exploration.

Prior to the time of glaciation the Williston Basin was covered with Tertiary sands and shales that had a thickness of up to 2,000 feet. These Tertiary formations were exposed to erosion. Hence the numerous stream channels present in the Tertiary surface were filled with reworked Tertiary or detrital material or with glacial drift. New channels were cut during each glacial period and filled with glacial debris. As a result we now have a great number of channels and sinks in the Tertiary that are filled with materials having a great variety of velocities.

These channels form buried low velocity zones having velocities varying between 3,000 and 5,500 feet per second and extending to a depth of up to 600 feet. As these low velocity zones are covered by some high velocity layer it is readily apparent, to a seismologist, that general reflection travel time correction procedures cannot be applied.

Low velocity zones are also caused by the draining of interstitial water out of formations by porous sandstone stringers and porous coal beds present in the Tertiary.

A typical seismic record of the Williston Basin will now be discussed.

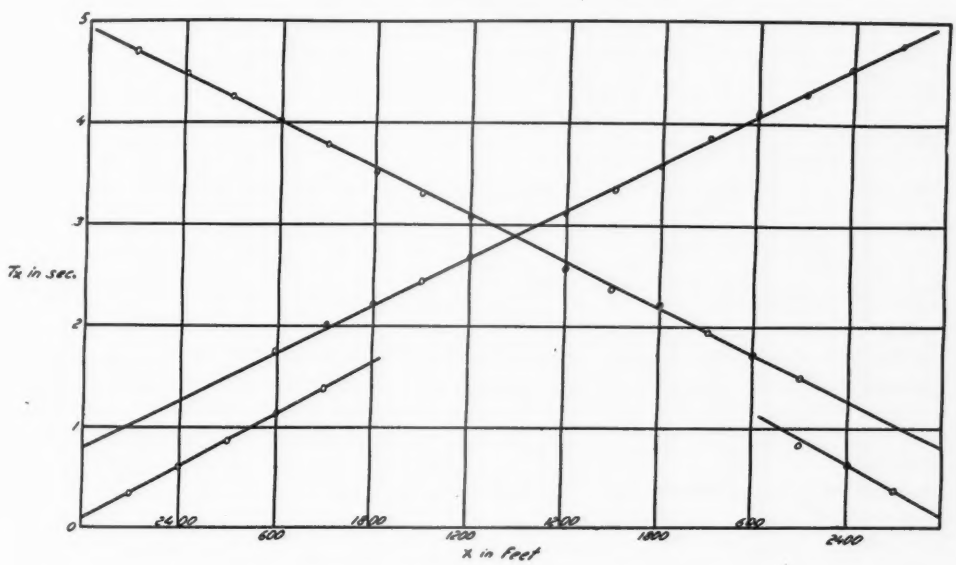


FIG. 4. Graph of the times of the first breaks versus the group distances from the shot point.

The first breaks of this record are as shown in Figure 3. The time of the first breaks versus the group distance from the shot point are plotted in Figure 4.

From the plot of t versus x in Figure 4 we get two layers with velocities of 5,900 and 6,500 feet per second. From the time versus depth plot (Fig. 5) of an uphole time survey at the same location we see that there are four different velocity layers present: a 15-ft-thick, 1,500 ft per second weathered material layer, a 50-ft-thick, 5,900 ft per second unweathered layer, an intermediate 116-ft-thick 3,000 ft per second low velocity layer and finally a 6,500 ft per second high velocity layer. Hence by just plotting the first break times versus the group distances from the shot point we missed the inter-

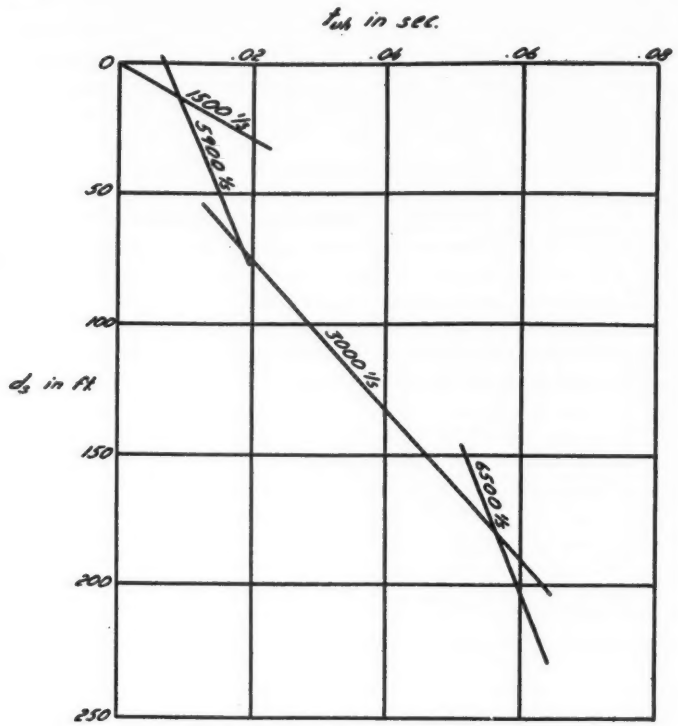


FIG. 5. Graph of uphole time versus shot depth.

mediate low velocity layer completely. (Velocity reversals can be only detected by uphole time surveys.)

From the nature of the first breaks from traces 1 to 5 we can also see that the energy transmitted through the thin high velocity layer is attenuated rapidly. It is also of importance that energy travelling in a thin layer is not only attenuated rapidly with distance but that the low frequency components of the first break energy are attenuated much more rapidly than the high frequency components.

Another rather unpleasant factor in interpreting seismic data in the Williston Basin is the presence of multiple reflections. Multiple reflections are often caused by large velocity contrasts at the interface of two subsurface layers. Such a large velocity contrast is present in the Williston Basin at the Mesozoic-Paleozoic contact. Those multiple reflections can be detected, however, because the data obtained from the Paleozoic reflections can be divided into two groups, according to their re-

spective moveouts (ΔT), one group having an extraordinary large moveout. The reflection data belonging in the large moveout group has been found to be due to multiple reflections.

One of the methods to simplify the recognition of primary and multiple reflections is to use long spreads and hence increase the moveout time difference between primary and multiple reflections.

In some parts of the Williston Basin, however, the multiple reflections are extremely disturbing as they come in at the same time as primary reflections from the Lower Devonian, Silurian, Ordovician, and Lower Paleozoic formations causing complicated interference patterns that can make record interpretations very complex.

As we can see from the exploration problems discussed it is not possible to find a definite seismic record interpretation method applicable to all parts of the Williston Basin but methods of interpretation have to be developed in each particular area.

The interpretation of reflections of the Paleozoic horizons will become more efficient as more information on the nature of the subsurface structures will become available by surveys made in the wells drilled.

To assist in making the near surface time corrections, core-hole samples should be taken frequently near the surface and up-hole velocity surveys should be made using each available core hole.

In conclusion, in view of the numerous irregularities of the various structures of the Williston Basin, it might be said that extensive cooperation between the many companies involved as well as good coordination of the available geological and geophysical data is necessary in order to insure the effective exploration of the Williston Basin.

GEOPHYSICS, VOL. XIX NO. 3 (JULY, 1954), PP. 582–585, 2 FIGS.

MEMORIAL

WILSON GORDON SAVILLE

Wilson G. Saville, senior partner of Gravity Meter Exploration Co., died at his home in Houston on February 14, 1954, at age 57, after a long illness. To his many friends in Houston and elsewhere, the untimely passing of such a vigorous and lively person came as an unexpected shock. It was characteristic that he did not wish his condition known or discussed among his friends although he had known for several months that his time was short.

Col. Saville had a strongly military background. He was born at Ft. Sill, Oklahoma while his father was a colonel stationed there. He graduated from West Point in 1918 and attended the Engineer Post Graduate School, Washington, D. C., 1918–20, receiving a Civil Engineering degree. His brother, his wife's father, and his two sons (one also a West Point graduate) were or are army officers. He resigned from the army in 1920 but re-entered the service during the Second World War, serving first as War Department district engineer at Galveston and later was assigned to the operational engineering branch, Supreme Headquarters, Allied Expeditionary Forces. He received the citations of Legion of Merit, the Bronze Star, the Order of the British Empire and the Croix de Guerre

with palm. The precision, quick decision, and dispatch of his actions in his business and geophysical contacts as well as his tall, erect personal carriage and good physical condition (he played a very sharp game of tennis until about four years ago) all reflected the military tradition.

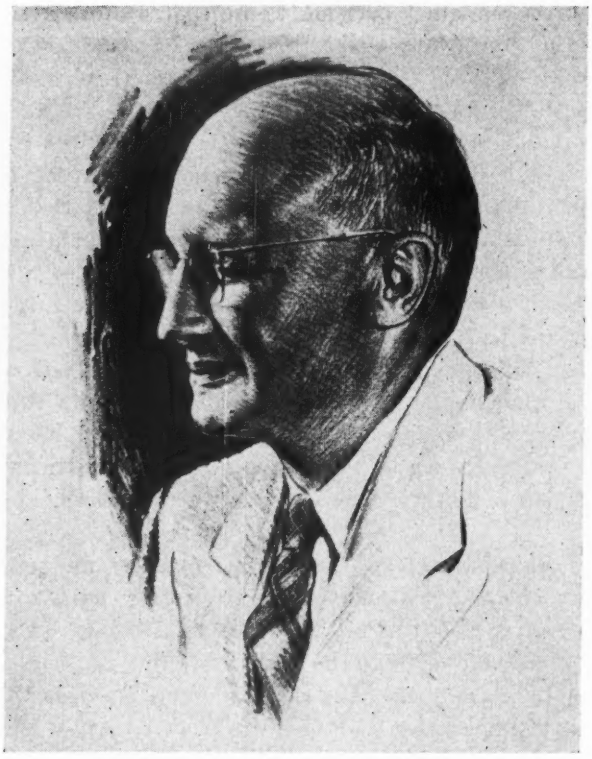
For a short time in 1920–21, Mr. Saville was engaged in mining engineering with the Phelps-Dodge Corp. in Bisbee, Arizona. From 1921 to 1925 he was scout, landman, and engineer with Amerada Petroleum Corp. in Tulsa and Rycade Oil Corp. in Houston. He was one of the pioneers in geophysical exploration. In 1925, with J. P. Schumacher, A. C. and R. Y. Pagan, he formed Torsion Balance Exploration Company to contract torsion balance surveys in the Gulf Coast. This company with its successor, Gravity Meter Exploration Co., is quite possibly the oldest continuously active geophysical contracting company still in operation. He was a member of the old Society of Petroleum Geophysicists which preceded the Society of Exploration Geophysicists, of which he was a member at the time of his death. He was a member also of the American Association of Petroleum Geologists and of the American Institute of Mining and Metallurgical Engineers.

Mr. Saville was very well known for his business and civic activities in Houston and particularly for his service for two terms (1946–1950) as chairman of the Houston-Harris County Port Commission. During this time some very substantial additions were made to the docks and other facilities operated by the Commission. He was a member of the Houston Club, Ramada Club, River Oaks Country Club, and Eagle Lake Rod and Gun Club.

Mr. Saville is survived by his widow, two daughters, Mrs. A. H. Hedden of Houston and Mrs. Myles Morris of New York City, and two sons, Rodman Saville of Houston and David B. Saville, a jet pilot, now serving in Japan, and a brother, General Gordon P. Saville, of the Air Force.

L. L. NETTLETON

MEMORIAL



LEONARD J. NEUMAN

Leonard J. Neuman died suddenly, of a coronary occlusion, on December 18, 1953. Although a bone ailment, multiple myeloma, had necessitated his using crutches for some time, he had been active in his consulting work up to the day of this heart attack.

Leonard was born in Little Falls, Minnesota April 2, 1900 but spent his boyhood near Libby, Montana. The history of his youth provides examples of the boundless energy that characterized his entire life. For pleasure he took long hunting trips, camping in the snow-covered mountains. On the more serious side was his service, as a 16 year old, as Assistant Ranger in the Forest Service. He enjoyed playing the trumpet in the high school orchestra, but had even more satisfaction in organizing and working as chief decker in a night-shift crew of high school boys that made production and safety records in a Libby saw mill.

He served as assistant in the physics laboratories, both while getting his degree in Electrical Engineering at Montana State and his M.S. in Physics and Mathematics at the University of Oregon. At Oregon he was also consultant to the Montana State Power Company. While obtaining his doctorate in physics at the University of California, as well as during the following years at the University of Santa Clara where he was Professor of Electrical Engineering, he con-

tinued consulting for various companies. The drive that demanded multiple outlets for his mental energy is illustrated by a story of this period. Walking through orchards near Santa Clara in the evenings, he noticed that the crickets chirped in regular cadence but that the cadence changed with the weather. He could not rest until, equipped with a metronome, wet bulb and thermometer—much to the worried puzzling of the orchard owners—he had made graphs proving that the cadence of the crickets could be predicted accurately from the humidity and temperature.

In 1930, Leonard left academic work and moved to Houston to serve as Director of Geophysical Research for The Texas Company. Four years later he joined Petty Geophysical Company as Research Consultant. In 1936, he went out for himself, doing geophysical, geological and evaluation work. He was successful financially but, as an associate of another company complained; " 'Doc' could make much more money if he weren't continually trying to reach beyond the present limits of our techniques." Assignments where the client selected difficult areas for seismic work pleased him, but his greatest satisfaction was with contracts where he could select the areas that he considered geologically promising. His interest carried through until the completion of wells and he has pending patent applications for the more accurate evaluation of possible reservoirs encountered in drilling.

Asked for his hobbies a few years ago, he listed hunting, fishing, music, biophysics, biochemistry, and plant pathology. Apparently he did not consider his work in various civic organizations and scientific societies as hobbies, nor did he feel the need to mention the aid, encouragement, and inspiration he could not help giving to numerous young men.

Indeed, he took his civic activities seriously. For several years, he served as delegate of the Gulf Coast Section of the AIME to the Houston Engineers Council, and he worked assiduously to make the first two symposia of the Council successes. Many members of the San Jacinto Chapter of the Texas Society of Professional Engineers will always remember his work as chairman of the Chapter's Fire Prevention Committee and his reports on the condition of the equipment of Houston's Fire Department and on Houston's fire record. Leonard was intensely interested in the conservation of natural resources and especially in Houston's water supply. For several years, he addressed meetings of civic organizations on the subject of water and conservation. At a meeting in Galveston, Leonard was appointed chairman of the Gulf Coast Water Commission. He was interested in sewage disposal, and he was one of the first to call attention to the growing smog menace in Houston. He served as president of the Texas Research Association for one year and on the Association's executive committee for many years.

Leonard is survived by Allison Parry Neuman whom he married in Berkeley in 1930 and by their daughter, Lee. Their loss is shared by the many associates who mourn the absence of a warm hearted and stimulating friend.

SHIRLEY L. MASON

CONTRIBUTORS

VIRGIL E. BARNES

VIRGIL E. BARNES received the B.S. and M.S. degrees in 1925 and 1927, respectively, from State College of Washington. He received the Ph.D. in 1930 at the University of Wisconsin. During the summers of 1924 through 1927 he was employed by the Washington Geological Survey, and did summer work for the Wisconsin Geological Survey in 1928, as well as for Dominion Explorers, Ltd. of Canada in 1929.

Dr. Barnes has held positions with the American Petroleum Institute (1930–1931) and the United States Geological Survey (1933–1935). He has been with The University of Texas Bureau of Economic Geology since 1935. His publications include Cambrian, Ordovician, and Devonian stratigraphy; economic geology; mineralogy; tektites; meteorites; oil field waters; field trip guides; earth temperatures; magnetic suceptibility; and joint papers correlating geology and geophysics.

Dr. Barnes has been a member of The American Association of Petroleum Geologists since 1931.

D. RAY DOBYNS has a background of 27 years of geophysical exploration. He received the degree of B.S. in Electrical Engineering from the University of Kansas in January, 1927. Upon graduation he was employed by Marland Oil Company where he did development work on gravity pendulum equipment. He worked as observer with the mechanical seismograph in 1928, and following this, worked with the first electrical seismograph equipment which Continental (that had taken over the Marland Oil Company) was developing. In 1933 he left Continental and went with Geophysical Research Corporation. In April, 1937 he joined Magnolia Petroleum Company where he is at present employed as Seismic Supervisor. He is a member of Society of Exploration Geophysicists, American Geophysical Union, Dallas Geological Society, and Dallas Geophysical Society. He was Secretary-Treasurer of the Dallas Geophysical Society upon its organization in 1947, and served as 2nd Vice-President in 1948, 1st Vice-President in 1949 and President in 1951.

D. RAY DOBYNS

WALLACE L. MATJASIC

WALLACE L. MATJASIC attended the University of Texas in 1927 and 1928. After spending several years with Humble Oil and Refining Company in Texas and Lago Petroleum Corporation in Venezuela he returned to school and received his B.S. degree from the University of Oklahoma in 1937. Upon graduation he immediately joined Honolulu Oil Corporation in California where he has since been in charge of their geophysical operations. He also served as District Geologist in Los Angeles from 1948 to 1953 and has been District Geologist in Bakersfield since 1953.

Mr. Matjasic is a member of the Society of Exploration Geophysicists and the American Association of Petroleum Geologists. He is a past President of the Pacific Coast Section of S.E.G. and of the San Joaquin Geological Society.

FIELDING M. MCGEHEE

FIELDING M. MCGEHEE, JR., attended Mississippi State College briefly in 1942; served 3½ years in the Signal Corps; received the B.S. and M.S. degrees in physics from the University of Alabama in 1948 and 1949, respectively, and the Ph.D. degree in physics from the University of Virginia in 1951. Since 1951 he has been in the Research Department of United Gas Corporation, Shreveport, Louisiana.

Dr. McGehee is a member of Pi Mu Epsilon, Sigma Pi Sigma, Sigma Xi, the Ark-La-Tex Geophysical Society, and the American Physical Society.

A. E. MCKAY

A. E. MCKAY received the B.S. Degree in Geology from the University of Oklahoma in 1928. From 1928 to 1937 he was employed by the Indian Territory Illuminating Oil Company, first as geologist and later as geophysicist. In 1937 he joined The Atlantic Refining Company as District Geophysicist, first in Shreveport, Louisiana, and later in Midland, Texas. He entered the United States Army in 1942 and returned to The Atlantic Refining Company's Dallas office in 1944 as Assistant Chief Geophysicist until 1950. He resigned from the Atlantic Refining Company in 1950 to go into the seismograph contracting business, and is now President of Continental Geophysical Company, Fort Worth, Texas. He was the first President of the Dallas Geophysical Society.

Mr. McKay is a member of the Society of Exploration Geophysicists, The American Association of Petroleum Geologists, American Geophysical Union, Fort Worth Geological Society, and Fort Worth Geophysical Society.

T. S. PETERSEN

T. S. PETERSEN, president and director of Standard Oil Company of California, first joined the company in 1922 as a service station salesman in Portland, Ore. He served in a variety of jobs throughout seven western states to become, in 1931, a division manager for Standard Stations, Inc., at Sacramento.

By 1938 Mr. Petersen had risen to the position of general manager of Standard Stations. Later that year, he became assistant to the president of Standard Oil Company of California, and manager of the Employee Relations and Personnel Department.

Mr. Petersen was subsequently named general manager of sales, Marketing Department, and in June of 1942, was elected to the board of directors. In December of the same year, he was named a vice-president. Five years later, on January 8, 1948, he was elected President of the company.

Mr. Petersen was born in Logan, Utah, in 1896 and moved to Portland with his family in 1912. He graduated from Washington High School, Portland in 1916.

He is a director of the Pacific Mutual Life Insurance Company, the American Petroleum Institute, and the Western Oil and Gas Association; a trustee of the California Academy of Sciences; consulting professor of marketing for the Stanford University graduate school of business, and a member of the Business Advisory Council for the U. S. Department of Commerce.

WILLIAM B. ROPER

WILLIAM B. ROPER attended the University of Texas from 1920 to 1923 where he majored in Civil Engineering. He operated his own construction business until 1931. He was associated with the Engineering Department of the Houston Oil Company from 1931 to 1933. He joined the Magnolia Petroleum Company in 1933 and became a torsion balance Party Chief a year later.

In 1938, Magnolia replaced the torsion balance with the gravity meter and he continued as Party Chief. In 1943 he became Supervisor in charge of Magnolia's gravity and magnetic operations and has continued in that capacity up to the present time.

Mr. Roper is a member of the Society of Exploration Geophysicists, the Dallas Geophysical Society, the American Geophysical Union and is a registered Professional Engineer by the Texas State Board of Registration for Professional Engineers.

BART W. SORGE

BART W. SORGE was graduated from the University of California at Los Angeles with an A.B. degree in Physics in 1933. He did postgraduate work in Physics at U.C.L.A., receiving an M.A. degree in 1934. Upon graduation, his geophysical experience began with the Rieber Laboratories as a development engineer, and later geophysical observer, party manager, and party chief. Since 1938 he has been employed by the United Geophysical Company, serving as a development engineer, computer, and party chief until 1943. At that time he became geophysical supervisor of United's western operations, and since 1947 he has been a vice-president of the company.

Mr. Sorge is a member of the Society of Exploration Geophysicists and the American Association of Petroleum Geologists. He is also a member of the Pacific Coast sections of these two societies. He served the SEG as Secretary-Treasurer, 1953–1954, and was chairman of the Special Committee on Safety, 1951–1953, and is still a member of this committee. He has been a member of the Standing Committee on Radio Facilities since 1948, and has been chairman of the Pacific Coast Regional Committee on Radio Facilities during the same time. He is now chairman of the Standing Committee on Membership, and is a member of the Special Committee on Permanent Building. As representative of the SEG Standing Committee on Safety, he is a member of the Central Committee on Accident Prevention of the American Petroleum Institute. He served on the SEG Arrangements Committee and the AAPG Technical Program Committee for the 1952 national convention.

C. A. SWARTZ

C. A. SWARTZ was graduated from the California Institute of Technology with the B.S. Degree in Physics in 1927, and the Ph.D. degree in Physics and Mathematics in 1931. During 1931 and 1932 he was employed as Research Physicist by the Union Switch and Signal Company in Pittsburgh, Pennsylvania, where he worked on the development of electronic signaling and control devices. From 1933 to 1944 he was a geophysicist with the Gulf Research and Development Co. engaged mostly in seismograph interpretation but including several years of field work and a year of electronic development. In 1944 he joined the Union Oil Company of California as Division Geophysicist in their Gulf Coast division in Houston. Since 1950 he has been with the United Geophysical Company in Pasadena as Research Geophysicist and supervisor of gravity and magnetic interpretation.

Dr. Swartz has been a member of the Society of Exploration Geophysicists since 1938.

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A. I. Levorsen

* SEG members.

Directors of the American Geological Institute

George E. Wagoner (Nov., 1954) — Sigmund Hammer (Nov., 1955)

Representative on Division of Earth Sciences National Research Council

C. B. Bazzoni (June, 1955)

Representative on Council of American Association for the Advancement of Science

Roland F. Beers, Beers and Heroy, Dallas, Texas

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the society. This publication does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees he should send it to the President within thirty days. Names of the references appear in parentheses after the name of each nominee.

ACTIVE

William Morrow Burney (O. D. Brooks, Sam Holland, R. C. Graham)
Luther Weldon Calahan (R. L. Lay, O. B. Hocker, E. H. Shannon)
Hollis O. Campbell (John M. Crawford, Cecil K. Jordan, Frank Searcy)
Joseph Bailey Evans, Jr. (R. M. Bradley, E. J. Gemmill, E. L. Current)
Robert Beach Fisher (John E. Owen, W. T. Born, James Harper)
Glenn Wayne Fordham (Tom Prickett, Jr., W. C. Bonebrake, J. P. Woods)
Thomas Edward Grimes, Jr. (Robert H. Ray, Robert S. Duty, J. C. Pollard)
Frank Victor Hendrickson (E. Joe Shimek, George Eldred Conwill, Homer L. Heggy)
Roger Kenneth Hodgson (C. J. Long, C. A. Willner, R. A. Gilmore)
Ralph H. Howe (W. Harlan Taylor, Sam D. Rogers, Don B. Winfrey)
Ornulf Logn (T. H. Vogt, Jens A. W. Bugge, H. Braekken)
John Daniel Moredock (William A. Watson, W. E. Hollingsworth, James E. Thompson)
Leighton Lyman Morse (Wilton W. LaRue, C. Bradner Brown, W. C. Merritt)
Harold Floyd Murphree (J. M. Desmond, V. E. Prestine, Dupree McGrady)
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Joe Jarvis Pitts (Robert H. Ray, Eugene Frowe, W. E. McCullers)
Marion Francis Pruitt (Stanley R. Allen, M. M. Slotnick, G. P. Montgomery)
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Johannes Roelf Vegter (B. D. Maree, J. F. Inslin)
Albert William Weeks (L. L. Nettleton, W. E. Hollingsworth, C. B. Bazzoni)
David Stewart Wilson (L. A. Markley, H. G. Patrick, C. S. Fleischmann)

TRANSFER TO ACTIVE

John Watson Britton (A. A. Brant, J. T. Wilson, S. H. Ward)
Robert Henry Brooks (J. J. Kidder, L. E. Twining, D. V. Bigelow)
John Henry Earl (William C. Lamb, W. B. Robinson, T. J. O'Donnell)
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Malcolm Argyle Knock (Paul D. Balbin, Karl Dyk, H. F. Patterson)
Royce Earl Lawson, Jr. (H. G. Patrick, C. S. Gleischmann, W. B. Duty)
Charles Wesley Nicholls (Dean Walling, B. B. Strange, William Fazakerly)
Louis Charles Pakiser, Jr. (H. R. Joesting, Mary C. Rabbitt, Paul L. Lyons)
Jack Maurice Proffitt (Cecil H. Green, Fred J. Agnich, Frederick E. Romberg)
Francis Raymond Reeves (Klaas van der Weg, V. E. Prestline, J. M. Desmond)

ASSOCIATE

Herbert Joseph Ackermann, Jr. (John Lee, Ralph Smith, John Palmer)
James Lester Arbogast (Charles Fay, Sidney Kaufman, Charles Vogel)
Claude L. Barker (Jesse E. Spencer, A. J. Hintze, George E. Wagoner)
Edward Russell Basye (F. Goldstone, R. B. Hale, F. A. Van Melle)

Harold Arthur Blum (John L. Martin, Henry F. Dunlap, Francis A. Collins)
Thomas Eugene Bullock (Nils H. Lago, James F. Carter, John L. Marlin)
Noel Clinton Burke (T. O. Hall, Jack Martin, P. M. Konkel)
Ransom Lee Burkett, Jr. (Thomas L. Allen, H. B. Smyrl, P. E. Narvarte)
Curtis Lee Chadwick (M. Holmes, G. W. McCoy, Thomas S. Napier)
Robert Lionel Comer (R. S. Mahanwah, J. W. Bowden, H. C. Maliphant)
Gunter William Conrad (A. E. McKay, C. J. Lomax, C. N. Page)
Edsel Kenneth Darby (L. F. Melchior, Sigmund Hammer, Philip Cerveny)
John Wesley Downs (W. Lee Moore, Paul Greenlee, Roland H. Carter)
Jimmie George Ducas (F. H. Agee, W. T. Gilland, J. A. Long)
Charles Eugene Ellison (K. A. Robertson, Edward G. Schempf, Miller W. Quarles)
Henry Esko Engman (F. A. Hale, R. E. Doe, W. Bannister)
Jack Foord Evernden (Perry Byerly, H. C. Bemis, C. A. Benston)
Gonzalo Fernandez (Rodolfo Martin, S. A. Alvarez Berros)
Aaron Frank Foster (R. H. Burton, J. C. Lusk, A. P. Mehringer)
William Carroll Fowler (F. A. Van Melle, F. Goldstone, W. Hafner)
Francis Craven French (J. B. Macelwane, L. N. Dexter, C. H. Hightower)
John Daniel French (H. H. Andrews, R. B. Baum, J. C. Davis)
Joseph Wincenc Fusso, Jr. (Elmer F. Blake, James B. Macelwane, Victor J. Blum)
William Henry Gilchrist, Jr. (C. J. Donnally, Richard Brewer, S. P. Weatherby)
James Thomas Hollis (Clinton H. Elliott, J. H. Pernell, C. G. McBurney)
George Atherton Howard (Earl Thomas, F. J. Agnich, C. H. Green)
Charles Lane Howell (H. A. Willis, W. H. Hawkes, G. L. Ellis)
John Alfred Hudson (T. A. Halbrook, E. A. Kiesler, C. M. Moore, Jr.)
Delmar Lee Igou (E. J. Gemmill, R. M. Bradley, W. R. Hughes)
James Hayward Johnson (R. F. Bennett, F. A. Smith, C. C. Sellers)
Joseph Dale Johnson (J. C. Ashby, C. G. Faubion, L. N. Dexter)
Herbert Gene Jones (J. E. Dorris, Carl G. Schauble, R. G. Couch)
Walter Dee Jones, Jr. (C. T. MacAllister, E. E. Jones, J. B. Ferguson)
Ernest Raymond Kanasewich (R. E. Brannian, T. A. Halbrook, C. M. Moore, Jr.)
John Sahlagle Kelly (Sidon Harris, T. I. Harkins, Paul H. Ledyard, John Daly)
Jerome James Kelly (John K. Godbey, M. B. Dobrin, J. E. White)
Ruben Wesley Knowles (R. E. Wright, Chester Sappington, T. O. Hall)
Joseph Alton Kornfeld (Paul L. Lyons, L. Y. Faust, R. W. Mossman)
Howard Emil Kringel (Paul M. Thompson, Chester P. Sappington, R. E. Wright)
Benjamin Lowe Langston (B. B. Strange, Dean Walling, W. B. Fazakerly)
Charles Edgar Ledbetter (R. D. Arnett, Charles C. Williams, Charles G. McBurney)
Robert Oscar Luehrmann (Gordon Cloepfil, Robert Dyk, Ray Wright)
Robert Earle MacDougall (L. B. Slichter, S. G. Sargis, H. V. W. Donohoo)
Charles Dana McKinney, Jr. (R. W. Lawrence, A. B. Austin, E. M. Shook, M. R. Budd)
Robert Luther Milliken (Herbert M. Dawson, Paul Greenlee, Leland Snow)
Howard William Oliver (Henry Joesting, Francis Birch, Robert Bean, John Adkins, Joel Swartz, J. Lamar Worzel)
Michael Robert Owens (Howard A. Willis, W. E. Hawks, George L. Ellis)
Alan John Phillips (W. Hafner, F. Goldstone, F. A. Van Melle)
George Marshall Sawyer (Robert J. Wells, John A. Adams, James M. Clinton)
Maynard DeVotie Shaw (R. J. Hughes, Paul Thompson, Chester Sappington)
Albert Anthony Slanis (E. M. Wolters, W. H. Courtier, J. W. Keffler)
John Stewart Sumner (William A. Longacre, Burton H. Boyum, Lloyal O. Bacon)
Jaap Willem Charles Mari Van der Sijp (A. Van Weelden, D. Dekker, O. Koefoed)
Richard Lee Wagner (C. F. Moore, Jr., L. J. Larguier, R. F. Bennett)

Sam Watkins Wahlers (S. B. Stewart, F. A. Smith, H. H. Happel, Jr.)
Chester E. Weaver (Carl H. Savit, John C. Stick, Jr., Dean C. Batchelder)
Clarence Frederick Wendenburg (D. P. Melton, E. W. Frowe, R. L. Palmer)
Harry Stuart Whitcomb, Jr. (T. E. Hobbs, A. A. Hunzicker, F. F. Reynolds)
Richard Edward Whitmore (Edgar Kraus, O. C. Clifford, Jr., C. H. Hightower)
Roy Paul Zilik (F. F. Reynolds, Hugh Porter, Jr., A. A. Hunzicker)
Dan R. Zalog (Robert Dyk, J. Frank Fuller, Robert Everett)

TRANSFER TO ASSOCIATE

Richard John Allenby, Jr. (C. Hewitt Dix, J. T. Wilson, F. G. Blake)
Richard C. Anderson (M. E. Trostle, R. H. Rainey, Robert Dyk)
John Peden Arkle, Jr. (J. R. Randolph, John A. Norden, R. C. Hilton)
Robert J. Black (A. E. McKay, C. J. Lomax, H. E. Stommel)
Harry Edward Blackburn, Jr. (Klaas van der Weg, W. M. Tottenham, John Hollister)
William Henry Broman (L. O. Bacon, F. Goldstone, F. A. Van Melle)
William R. Brown (J. A. Harris, Gordon M. Frey, H. E. Stommel)
Jorge Enrique Castillo (John C. Hollister, George T. Merideth, R. R. Kitch)
Donald Harry Clements (George Anderson, John Foster, James T. Wilson)
Thomas John Ellis (John C. Hollister, George T. Merideth, Ross Smith, Jr.)
Robert Theodore Goodfellow (Julian K. Pawley, N. R. Park, John C. Hollister)
Bernard Henry Griesedieck, Jr. (L. N. Dexter, C. H. Hightower, Victor J. Blum)
Don Allred Hansen (S. G. Sargis, L. B. Slichter, Kenneth Cook)
John Lincoln Howell (C. H. Dix, G. W. Potapenko, George Shor)
Stuart Allison Jones (John C. Hollister, Karl Dyk, M. B. Widess)
Wilbur Edwin Jordan (J. C. Hollister, A. A. Brant, H. E. Stommel)
Dennis Robert Lucas (J. A. Harris, O. A. Poirier, Irvin B. Murray, Jr.)
Ian Havelock Mackay (John C. Hollister, F. Hale, Robert Doe)
Frank Xavier Mara (James B. Macelwane, Victor J. Blum, Howard Willis)
Willard Aaron Maxey (George W. Reed, J. R. Maxey, N. J. Christie)
Thomas Owen May (Neal J. Smith, J. W. Northrop, K. E. Burg)
Wilfred C. Mosier (S. C. Stoneham, P. E. Swenson, H. C. Bemis)
Harry Ralph Nicholls (D. J. Van Nostrand, Robert Gallagher, E. A. Blomerth)
Elliott Bonnell McConnell, Jr. (R. M. Nugent, B. F. Howell, J. T. Geer)
Timothy Daniel O'Leary (Victor J. Blum, James B. Macelwane, Jack M. Desmond)
Harry Dale Orcutt (C. Frey, E. B. Wasson, J. A. Harris)
Ned Allen Ostenso (G. P. Woollard, W. E. Bonini, J. S. Sumner)
Lee Hawke Price (Cecil Green, A. E. Storm, N. W. Mann)
Donald Harold Quam (John C. Hollister, O. A. Poirier, Robert Dyk)
Ronald Rex Taylor (Harold O. Seigel, W. O. Cartier, Homer Jensen)
Victor Withstandley III (Perry Byerly, Roland F. Beers, W. B. Heroy)

ADDITIONAL MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

ACTIVE

Thomas R. Cheesman (B. E. Richert, S. E. Bills, George McAlpine)
Donald Ray Clark (S. O. Patterson, D. B. Robinson, J. A. Smith)
Barney Melvin Crow (H. G. Patrick, O. D. Brooks, Sam B. Holland)
Mrs. Anne Robins Frank (John L. Bible, E. E. Jones, R. J. St. Germain)
William Gordon McCoy (Frank O. Mortlock, R. B. Kerbow, Carl M. Wert)
George Oliver Morgan, Jr. (H. G. Patrick, Merrill Smith, W. B. Duty)
J. Lawrence Muir (Andrew Gilmour, Francis Faulkner Campbell, W. B. Hogg)
Homer N. Opland (David F. Bleil, H. E. Stommel, Ben S. Melton)

Rodney Thirsk Phipps (J. A. Smith, S. A. Kerr, D. Robinson)
Harold Hutchinson Prichard (C. H. Hightower, J. C. Ashby, H. H. Nogami)
Cecil Taylor Rhodes, Jr. (Paul Greenlee, Gordon Kirby, Leland Snow)
Charles Vavere Schroll (L. L. Nettleton, N. C. Steenland, Irving M. Griffin, Jr.)
George Rogers Smith (John L. Bible, Jack B. Ferguson, Eugene P. Evans)
Edwin H. Strand (D. B. Robinson, S. Kahanoff, J. A. Smith)
Thomas W. Swafford, Jr. (J. D. Perryman, W. B. Heroy, Jr., R. A. Arnett)
Lloyd Rex Travis, Jr. (C. A. Weeth, G. E. Bader, J. A. Brooks, Jr.)
Loyal Hamilton Wells (J. R. Walker, Virgil W. Teufel, E. L. Caster)

TRANSFER TO ACTIVE

Robert E. Crandall (Phil P. Gaby, George Augustat, D. L. Pretzer)
Robert Van Coleman, Jr. (M. C. Kelsey, E. F. McMullin, J. F. Rollins)
Alvin Hollis Clement (Harold R. Frank, Harold R. Prescott, L. E. Whitehead)
Wayne H. Denning, Jr. (Leslie C. Spencer, Jesse E. Spencer, F. L. Travis, Jr.)
Quin Hayes (O. H. Armstrong, Paul E. Nash, W. F. Lechtenberg)
George Donald Hobson (J. L. Burns, I. C. Mayfield, L. I. Freeman)
Thomas Carroll King (Gordon Kirby, T. G. Arnold, Craig Ferris)
Philip L. Lawrence (M. B. Dobrin, J. E. White, G. T. Meredith)
John Alexander MacMillan (C. M. Moore, Jr., A. G. Harvey, T. A. Halbrook)
William Alexander Robertson (F. A. Hale, Phil P. Gaby, E. A. Kiesler)
William A. Seal, Jr. (A. E. McKay, C. J. Lomax, C. N. Page)
Robert Burns Shaller (Cecil H. Green, F. J. Agnich, John H. Wilson)
George G. Shor, Jr. (Beno Gutenberg, John D. Marr, Burton Hinton)
Russell William Stephenson (C. H. Green, W. L. Fraser)
William Oliver Smith (John A. Veeder, Carl F. Barnhart, John F. Hosterman)
Jim Roy Williams (E. F. Blake, P. I. Bediz, R. E. Davis)

ASSOCIATE

James Alan Ballard (B. B. Robinson, F. W. Lau, E. B. Claunch)
Edward Woodson Beall (Ewin D. Baby, Phil P. Gaby, Dwayne L. Pretzer)
Dillard Lee Brooks (R. H. Glover, L. B. Trombla, F. F. Campbell)
John Blades Cameron (Perry Byerly, J. Evernden, H. A. Willis)
Marco Antonio Campodonico (J. B. Ferguson, Ray St. Germain, Merrile Smith)
Hoyt Frank Casteel (William J. Cunningham, E. W. Matthews, A. A. Milton)
Jesse Theodore Cherry, Jr. (J. E. Walker, R. B. Hale, W. Hafner)
Donald Lee Crum (F. F. Reynolds, A. A. Hunzicker, A. P. Marsh)
Gilbert Edward Dawson (Carl L. Bryan, Carl M. Wert, T. J. O'Donnell)
James Britton Dill (James A. Kurfess, William G. Hickle, S. J. Allen)
Gerald Raymond Gauvin (Orley E. Prather, Delord R. Mabry, Harry Harris)
Rex Golson, Jr. (O. B. Manes, J. R. Randolph, R. C. Hilton)
Gordon Lee Gray (J. A. Ballard, Wm. M. Erdahl, L. B. Trombla)
Winston B. Howard (William E. Shafer, Lawrence K. Morris, Walter R. Fillippone)
Charles Stephen Kaufman (R. S. Finn, John Owen, Jack L. Friendly)
Raymond Edward Kay (C. V. A. Pittman, E. C. Regaor, W. R. Ransone)
William Stafford McPhee (A. A. Fitch)
Azard Mardirosian (T. L. Kunkel, D. T. McCreary, Alton McClung)
Lucien Thomas Martin (Julian C. Ashby, Henry H. Nogami, H. Raymond Livingston)
Clellen Gaston Mooss (J. R. Gilliland, Ashton Crain, O. B. Reynolds, Jr.)
Clarence R. Nigh (Paul Greenlee, Gordon Kirby, Leland Snow)
George Robert Perkins (W. W. Clark, W. E. Martin, E. F. Blake)
William Freeman Pettus (Perry R. Love, Glenn M. McGuckin, James M. Wilson)
Mary Stella Phillips (W. M. Rust, V. L. Redding, D. H. Gardner)

Harold Arthur Pike, Jr. (J. B. Ferguson, Ray St. Germain, Merrill Smith)
Max Plotkin (David S. Seabrooke, G. L. Sorour, E. Lipsett)
August Leo Pugh (A. C. Yokubaitis, Joe L. Ferguson, G. A. Berg)
Lloyd Henry Rhodes II (C. J. Long, C. A. Willner, R. A. Gilmore)
James William Rogers (Otis B. Hocker, D. T. McCreary, LeRoy McCravey)
Willia Lee Russell, Jr. (Robert H. Ray, Robert S. Duty, G. D. McElree, Jr.)
Thomas A. Tarter, Jr. (C. B. Forbes, Nils Lago, J. D. Rookus)
Jack Hugh Thompson (J. E. Thompson, R. W. Beard, William A. Watson)
Sheridan William Tift (Kenneth E. Gibbs, John D. Horton, Dale E. Turner)
Jack Henry Veasaw (G. H. Samuels, W. W. Ogden, B. B. Hughson)
Richard Lewis Wegemer (D. M. Weber, L. F. Melchior, H. A. Durbin)
Lawrence Gill Wimpey (C. G. Flittle, C. F. Sellers, A. E. Storm)
Delmar Wright (H. A. Sears, David Sheffet, John J. Jakosky)

TRANSFER TO ASSOCIATE

James Richard Bingel (Ralph C. Holmer, John Hollister, Thomas P. Anderson)
Edmund Ralph Blakeman (Frank Ittner, Cecil E. Reel, Dale E. Turner)
Frederick Braitling Fowler (John C. Hollister, Henry F. Dunlap, Stuart C. Mut)
William Wallace Kerr (M. G. Frey, J. C. Hollister, H. E. Stommel)
Daniel James Novak (T. O. Hall, Eugene L. Current, Robert R. Singer)
Melvin Earl Putnam (R. W. Mossman, J. N. Wilson, W. B. Agocs)
William Miller Walton, Jr. (John A. Norden, W. W. Clark, Bryan A. Duby)
David Henry Warren (Roland F. Beers, Maurice Ewing, S. C. Stoneham)
Bruce Cady Wentner (R. D. Everett, R. H. Rainey, Robert Dyk)

MINUTES OF THE 24TH ANNUAL BUSINESS MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

APRIL 13, 1954—ST. LOUIS, MO.

The meeting was presided over by Roy L. Lay, President of the Society, who called the meeting to order at 3:15 P.M. President Lay called attention to the fact that an annual business meeting is required by the Constitution and Bylaws of the Society.

Father Macelwane gave a supplementary report for the Standing Committee on Geophysical Education which is published elsewhere in this issue. The original report is appended to the minutes of this meeting as Exhibit F.

President Lay called attention to the fact that this year all the committee reports were distributed in booklet form to all those attending the meeting, and urged those attending to read these reports.

President Lay then introduced the new officers as follows:

PAUL L. LYONS, President: Mr. Lyons expressed his appreciation for the honor bestowed upon him and asked the assistance of the whole membership in order successfully to carry on the affairs of the Society during his term of office.

ROY F. BENNETT, Vice-President: Mr. Bennett thanked the membership for their support and asked for the submission of papers for the next joint meeting at New York City in the spring of 1955.

H. M. THRALLS, Secretary-Treasurer: Mr. Thralls stated that Secretary-Treasurers should neither be seen nor heard and made no further comments.

MILTON B. DOBRIN, Editor: Mr. Dobrin briefly discussed some of the changes in editorial policy of GEOPHYSICS made during the last year and announced that he now has the assistance of five capable associate editors.

After the completion of introduction of officers, President Lay asked if there was any further

business to come before the meeting. Since none was offered he declared the business meeting adjourned at 3:25 P.M. The following reports are appended to these minutes.

Report	*Exhibit*
President	A
Secretary-Treasurer	B
Auditor	C
Editor	D
Standing Committee on Program and Arrangements	E
Standing Committee on Education	F
Standing Committee on Distinguished Lectures	G
Standing Committee on Radio Facilities	H
Standing Committee on Membership	I
Standing Committee on Honors and Awards	J
Standing Committee on Reviews	K
Standing Committee on Public Relations	L
Standing Committee on Publications	M
Standing Committee on Geophysical Activity	N
Standing Committee on Student Membership	O
Standing Committee on Safety	P
Special Glossary Committee	Q
Special Committee on Student Essay Contest	R
Special Committee on Business Office Survey	S
Geophysical Case Histories Committee—Volume II	T
Constitution and Bylaws Committee	U
Advisory Committee on Radioactive Mineral Exploration	V
American Geological Institute Director	W
National Research Council Representative	X
American Association for the Advancement of Science Representative	Y
Special Committee on Code of Ethics	Z
Permanent Building Committee	AA

Respectfully submitted,
BART W. SORGE, *Secretary-Treasurer*

EXHIBIT A. REPORT OF THE PRESIDENT

Following the annual meeting in Houston, Texas, in March 1953, Chairmen were appointed by the President for the following standing committees: Membership, Honors and Awards, Education, Student Membership, Distinguished Lectures, Public Relations, Publicity, Geophysical Activity, Safety, Reviews and Radio Facilities. Special Committees were appointed as follows: Constitution and Bylaws, Permanent Building, Code of Ethics, Student Essay Contest, Business Office Survey, Glossary, Geophysical Case Histories Volume II, Radioactive Mineral Exploration. Representatives were appointed to the National Research Council, American Association for the Advancement of Science, and American Geological Institute.

During the 1953–54 term five Executive Committee meetings were called by the President and an unusually large volume of business transacted as listed in the report of the Secretary-Treasurer.

In accordance with the Constitution and Bylaws, the President, as a member of the Executive Committee, reviewed each and every application for membership and handled a large volume of correspondence associated with the Society's affairs.

Considerable time was spent working out problems associated with our business office brought about by the recent rapid growth of SEG. The office was moved to much more adequate quarters and, through the efforts of the Secretary-Treasurer and the Business Office Survey Committee, it is now functioning much more efficiently and is in a better position to serve the members of the Society.

In anticipation of the future growth of the Society, a Permanent Building Committee was appointed to study the feasibility of financing a permanent home for the SEG business office in keeping with the dignity of our Society.

The project of publishing a vocational brochure entitled "Careers in Exploration Geophysics," authorized by the Council in 1953, at Houston, is almost complete and its financial success is virtually assured. The Student Essay Contest was initiated during the year and should do much in future years to further the interest of students in Geophysics.

The President visited many of the local sections during the past year and delivered addresses to the following groups: Second Annual Meeting of the Permian Basin Geophysical Society, at Midland, Texas; Fort Worth Geophysical Society; Canadian SEG in Calgary; Annual Joint Meeting of the Pacific Coast Section of AAPG, SEG and SEPM, at Los Angeles; Seventh Annual Midwestern Exploration Meeting, at Dallas, Texas; University of Texas graduate students in Geology. The President participated in the dedication of a seismograph station donated by the Dallas Geophysical Society to the Southern Methodist University. The South Texas Geophysical Society at San Antonio, Texas and the Casper Geophysical Society were affiliated with SEG during the year. Visits were made to Billings, Montana and New Orleans, Louisiana to assist in the organization of local SEG sections, both of which are now affiliated with SEG. The President worked with the Standing Committee on Student Membership in the organization of the Houston Student Section on SEG. The final address will be given at St. Louis during the annual meeting.

The Society continued to show a very healthy growth in membership, increasing from 3,366 to 4,138 at the end of 1953. In view of this growth, the Executive Committee gave a great deal of thought to the subject of future annual meetings and after very serious deliberation with the advice and consultation of many members and the officers of a large majority of the local sections, it was the consensus that the better interest of our Society could be served by holding future annual meetings at points more closely located to the geographical center of our membership. The first separate annual meeting of SEG will be held October 3–6, 1955, in Denver, Colorado. Headquarters will be the Shirley-Savoy Hotel. It was realized this major step would initiate a new era but at the same time it was considered a forward movement. It is the sincere hope of the Executive Committee that this change in meetings will prove beneficial by permitting many more SEG members to attend future annual meetings than would be possible otherwise.

I would like to express my sincere appreciation to the Executive Committee, the chairmen and members of all committees, the officers of the local sections, and Mr. Colin C. Campbell for the faithful and conscientious support which they have given to me during the past year and for their unselfish and untiring efforts in promoting the interests of our Society. With their splendid support, my term of office has been most enjoyable and a pleasant experience which I shall always remember.

ROY L. LAY, *President*

Houston, Texas
March 19, 1954

EXHIBIT B. REPORT OF THE SECRETARY-TREASURER

The period covered by this report is from the Joint Annual Council Meeting at Houston, March 23, 1953, to April 12, 1954.

As a result of the continued rapid growth of the Society and the many additional problems associated with this growth, the Executive Committee of the S.E.G. found it necessary to hold five formal meetings during the year—one in Houston, March 26, 1953, three in Dallas, May 23, June 27, and November 11 to 13, 1953, and one in St. Louis, April 11 and 12, 1954. Additional business was handled by telephone, telegraph, and correspondence.

As of March 24, 1954, a total of ninety-one Executive Orders were issued during the year, of which eighty-five concerned membership applications, transfers, and resignations. The other six Executive Orders were as follows:

No. 393—August 17, 1953—Authorized Midwestern, Pacific Coast, and Eastern Regional Meetings.

No. 406—October 2, 1953—Authorized affiliation of Houston Students' Section.
No. 409—October 23, 1953—Accepted petition of Geophysical Society of South Texas to become local section.
No. 412—November 4, 1953—Authorized employment of a bookkeeper.
No. 443—March 1, 1954—Accepted petition of Southeastern Society to become a local section.
No. 455—March 23, 1954—Accepted petition of Montana Society to become a local section.

Following are the essential actions taken at the Executive Committee Meeting of March 26, 1953:

(1) Worked out details of affiliation between SEG and the European Association of Exploration Geophysicists.
(2) Discussed problems of the business office of the Society and the possible transfer of duties from the Editor to the Business Manager.
(3) Recommended to the President that he appoint a Special Committee to study the problems of the Society's business office.

Major actions taken at the meeting in Dallas, May 23, 1953, were as follows:

(1) Decided to procure larger quarters for the Society's business office, as recommended by the Special Committee.
(2) Decided to hire additional full-time assistant for the business office.
(3) Discussed the advisability of having associate editors. The Editor has the necessary authority under the Constitution and Bylaws to appoint associate editors should he wish to do so.
(4) Discussed problems pertaining to annual meetings.

At the meeting of June 27, 1953, in Dallas, the major items discussed were:

(1) Problems of future annual meetings.
(2) Details of affiliation between the SEG and EAEG.
(3) Problem of District Representatives in areas not covered by local SEG sections.
(4) The preliminary report of the Glossary Committee.
(5) Problems of the SEG business office.

At meetings of the Executive Committee, November 11 to 13, 1953, at Dallas, the following major actions were taken:

(1) The SEG will hold separate annual meetings after the New York meeting in the spring of 1955.
(2) The first separate annual meeting will be held in the fall of 1955.
(3) The President will appoint a committee to study changes in the Constitution and Bylaws as a result of the change in annual meetings.
(4) The President will appoint a general chairman for the first separate annual meeting.
(5) Adopted recommendations by the Secretary for handling certain membership problems.
(6) Declined to grant special consideration to applicants for Active Membership who spend considerable time as graduate students.
(7) Changed the method of remuneration for the Business Manager.
(8) Declined to donate publications of the Society to universities and other institutions.
(9) Decided to ask the Membership Committee to clarify qualifications for Active Membership.

At the Joint meeting of the incoming and out-going Executive Committees, April 11 and 12, 1954, at St. Louis, the following major actions were taken:

(1) Decided to print 100,000 copies of the Vocational Guidance Brochure.
(2) Changed the fiscal year of the Society from a calendar year basis to July 1-June 30.
(3) Approved the purchase and installation of an Addressograph system in the business office.
(4) Determined matter of policy pertaining to the separate annual meetings.

(5) Discussed the relationship between the SEG and AGI.
(6) Decided to limit back dues of dropped members to an amount equivalent to one year's dues.

The Treasurer's report is for the calendar year 1953 and presents actual financial statements for 1951, 1952, and 1953, as well as an estimated operating budget for the calendar year 1954. The 1954 budget is subject to modification by the Council at its meeting April 12, 1954, as well as action by the Executive Committee during the year.

	1951	*1952*	*1953*	*1954 Budget*
Income				
Membership Dues	$20,668.00	$24,403.00	$30,281.50	$32,000.00
GEOPHYSICS	24,538.88	28,440.57	34,266.86	37,500.00
Geophysical Case Histories	711.05	848.00	1,116.60	1,000.00
Cumulative Index	77.45	38.00	16.20	—o—
Commissions Rec'd	182.67	1,295.28		
Interest Rec'd	125.00	337.11	360.43	400.00
Other Income		1,428.88	6,246.10	3,000.00
Total Income	$46,303.05	$56,790.84	$72,287.69	$73,900.00
Expense				
Operating Expense	$22,423.05	$31,151.69	$46,971.91	$41,575.00
Publication Cost	16,462.16	24,509.28	24,785.11	26,000.00
Total Expense	$38,885.21	$55,660.97	$71,757.02	$67,575.00
Net Income	$ 7,417.84	$ 1,129.87	$ 530.67	$ 6,325.00

Note: The above estimated margin of profit for 1954 does not include possible publication expense of the Vocational Guidance Brochure, Cumulative Index, Index of Wells Shot for Velocity, Geophysical Case Histories, Volume II, and re-printing of back numbers. Also not included are expenses for possible distinguished lecture tours. All of the above projects are supposed to be self-liquidating.

The decrease in net income for 1953 has continued as compared to earlier years. This decrease is largely due to increased printing costs, the decision to move the business office into larger quarters, and the expense of preparing and printing the first issue of the Vocational Guidance Brochure. The rapid expansion of the membership of the Society was responsible for a moderate increase of expenditures for all purposes as compared to previous years. It is of interest that the increase in advertising rates, established by the Executive Committee late in 1952, became only partially effective during the calendar year of 1953. This was due to the fact that about half of all advertisers operated on two-year advertising contracts which were already in effect at the time the increase was decided upon. The year 1954 will see the full benefits as a result of this increase in advertising rates.

The balance sheet for December 31, 1953, shows that the Society is continuing to have a strong cash position. Reserves are adequate and no difficulties are anticipated to finance the Society's operations during the coming year.

In cooperation with the Special Committee on the Business Office Survey, the functions and space requirements of the business office were studied. As a result, the business office was moved into larger quarters which will be adequate for several years.

Efforts were made throughout the year to improve the efficiency of the Society's business office. Some unnecessary functions were eliminated. Special work done for some of the Society's committees was placed elsewhere, and some unprofitable operations were abandoned.

In order to study first-hand a business office servicing the needs of about 11,000 members, a

special trip was made to the business office of the American Philatelic Society at State College, Pennsylvania. Several days were spent studying methods and procedures which make it possible to operate a business office efficiently with the same or smaller personnel than that of the SEG and yet satisfy the needs of a larger membership.

As a result of this visit, changes of a strictly business nature have been instituted in the SEG business office. Approval of other changes has been requested and received from the Executive Committee. Additional recommendations have been made to the Executive Committee for changes in the Constitution and Bylaws, leading to more efficient and economical handling of the Society's membership problems. At a conference with the auditors and the Business Manager, certain changes were made in the accounting procedure to simplify the work of the business office.

All these suggested changes have been made with the point of view of easing the workload on the staff of the business office and making their work more efficient, resulting in better and more economical service to the membership. The wholehearted and willing cooperation of the Business Manager, Colin Campbell, and his staff in this endeavor is greatly appreciated.

As a result of discussions with other members of the Society's Executive Committee, it was decided to prepare an operating manual or procedural guide for the Society's activities. Included in this manual are the various functions carried out by the business office, and details of activities for the various officers of the Society and all of the Standing Committees. Many of these activities are not spelled out in detail in the Constitution or Bylaws. As a result, this operational manual should prove of value to new officers and chairmen of standing committees. It should also result in a more uniform and continuous procedure on the part of the business office. The cooperation of the Society's officers and Chairmen of the Standing Committees in this project is very much appreciated.

It has been a privilege to serve the Society as Secretary-Treasurer during the past year, a task which I have enjoyed very much.

BART W. SORGE, *Secretary-Treasurer*

EXHIBIT C. REPORT OF THE AUDITOR

LYBRAND, ROSS BROS. & MONTGOMERY

Certified Public Accountants

To the Executive Committee,
Society of Exploration Geophysicists

We have examined the balance sheet of the Society of Exploration Geophysicists as of December 31, 1953 and the related statement of income for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances except that, in accordance with the terms of our engagement, we did not obtain confirmation of the accounts receivable from members and others.

In our opinion, subject to the above comments relating to the confirmation of accounts receivable, the accompanying balance sheet and related statement of income present fairly the financial position of the Society of Exploration Geophysicists at December 31, 1953 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a consistent basis except as to the change in the method of accounting for back issues of GEOPHYSICS.

LYBRAND, ROSS BROS. & MONTGOMERY

Tulsa, Oklahoma,
March 10, 1954

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—DECEMBER 31, 1953

ASSETS

Current Assets:		
Cash		$26,052.55
Accounts receivable:		
Membership dues	$ 3,212.00	
Advertising and other	4,439.54	
	7,651.54	
Less: Allowance for doubtful accounts	1,357.08	6,294.46
Inventory of publications (Note A)		827.00
TOTAL CURRENT ASSETS		$33,174.01
Investments:		
United States Savings Bonds, at cost	$13,880.00	
Stock of Container Corporation of America	442.50	14,322.50
Fixed Assets:		
Office furniture and equipment	$ 7,536.72	
Less: Allowance for depreciation	1,765.63	5,771.09
Prepaid Expenses and Deferred Charges:		
Prepaid postage, insurance and other	$ 706.74	
Deferred agency commissions and discounts	594.77	1,301.52
		$54,569.11

LIABILITIES AND MEMBERS' EQUITY

Current Liabilities:		
Accounts payable		$ 1,570.42
Deferred Income:		
Membership dues paid in advance	$22,032.44	
Subscriptions to and advertising in GEOPHYSICS paid in advance	4,003.80	26,036.24
Members' Equity:		
Balance, December 31, 1952	$25,989.28	
Net income for the year (Exhibit B)	530.67	
Fair market value of stock donated during year	442.50	
BALANCE, DECEMBER 31, 1953		26,962.45
		$54,569.11

NOTE A:

By action of the Executive Committee in November, 1953, the future printing orders of the quarterly publication, GEOPHYSICS, are to be increased to provide a more adequate supply of back numbers for new members and subscribers. Accordingly, the back numbers of GEOPHYSICS, starting with the four issues of 1953, are to be valued at their respective selling prices and included in the balance sheets. At December 31, 1953 the amount so included was $827.

The inventories of back issues of GEOPHYSICS issued prior to 1953 and of other publications are estimated at their respective selling prices to be approximately $16,000 which, in accordance with practices of prior years, have not been reflected in the balance sheet at December 31, 1953.

SOCIETY OF EXPLORATION GEOPHYSICISTS
STATEMENT OF INCOME
FOR YEAR ENDED DECEMBER 31, 1953

Income from Operations:		
Membership dues		$30,281.50
GEOPHYSICS magazine, etc.:		
Advertising	$22,705.73	
Subscriptions	7,252.58	
Back numbers	3,213.99	
Microcards of back numbers	361.00	
Reprints	1,094.56	
Index of wells	507.90	
Cumulative Index to GEOPHYSICS	16.20	
Discounts allowed	(879.71)	34,272.25
Geophysical Case Histories, Vol. I		1,116.60
Commissions:		
Sales of books published by others	$ 1,630.65	
Sales of microcard readers	139.00	1,768.65
Miscellaneous:		
Interest received	$ 360.43	
Gain on sale of Fixed Assets	202.96	
Other	373.50	936.89
		$68,375.89
Publication Costs and Expenses:		
Publication Costs—Schedule I)	$30,180.26	
Operating Expenses—(Schedule II)	37,667.35	67,857.61
Net income from operations		$ 518.28
Safety Committee Posters:		
Income from sale of posters	$ 3,235.05	
Expense—Cost of printing posters	3,298.91	
Net loss from Safety Committee operations		(63.86)
Distinguished Lecture Tour:		
Billings to section offices	$ 800.00	
Expenses of lecture tour	723.75	
Net income from lecture tour		76.25
TOTAL NET INCOME—(Exhibit "A")		$ 530.67

SOCIETY OF EXPLORATION GEOPHYSICISTS
PUBLICATION COSTS AND OPERATING EXPENSES
FOR YEAR ENDED DECEMBER 31, 1953

Publication Costs—Schedule I

GEOPHYSICS, Volume XVIII	*Copies*	*Amount*
No. 1, 352 pages	5,000	$ 5,863.74
No. 2, 312 pages	5,000	5,991.36
No. 3, 356 pages	5,000	6,585.22
No. 4, 336 pages	5,000	6,344.79
		$24,785.11
Less: Inventory December 31, 1953, priced at $1 per copy		827.00
Reprints		1,966.33
Microcards of GEOPHYSICS (back numbers)		288.19
Index to wells		2,194.83
Membership lists		1,672.80
		$30,180.26

Operating Expenses—Schedule II

Salaries:	
Business manager	$ 5,000.00
Business office employees	6,783.25
Commissions:	
Advertising—business manager	4,999.52
Advertising—agencies	2,958.23
Subscriptions—agencies	553.10
Office rent	1,657.00
Utilities	145.68
Postage	2,574.47
Stationery and office supplies	3,581.08
Telephone and telegraph	672.95
Auditing	350.00
Depreciation of office equipment	1,005.88
Advertising and subscriptions	174.91
Provisions for bad debts	1,131.58
Federal insurance contributions tax	158.48
Annual meeting expense	167.31
Regional meeting expense	83.15
Contributions	1,000.00
Glossary	119.88
Vocational guidance brochure	1,976.55
Purchase of special publications	1,362.28
Microcard readers	276.65
Traveling expense	137.98
Miscellaneous	807.42
	$37,677.35

EXHIBIT D. REPORT OF THE EDITOR

During the year since the Society's last Annual Meeting, an important change has been made in the handling of editorial business for GEOPHYSICS. Five associate editorships have been created to expedite the technical evaluation of manuscripts. The first group of associate editors under the new plan of organization was appointed late in 1953. The new arrangement has already turned out to be quite successful in reducing the Editor's work load. It has also aided in systematizing the evaluation procedures for manuscripts so as to insure a good supply of competent referees for papers covering all phases of exploration geophysics. The Associate Editors, Dr. Norman Ricker, Dr. L. Y. Faust, T. A. Elkins, Prof. Victor Vacquier, and Dr. Irwin Roman, are all distinguished members of the geophysical profession and the Editor feels most fortunate to have the benefit of their consultation.

The four issues of GEOPHYSICS from July, 1953 to April, 1954 contained 45 technical papers and a total of 735 pages of technical material. This represents an average of 11 papers and 184 technical pages per issue as compared with 14 papers and 231 technical pages per issue during the last year that my predecessor, Mr. Paul Lyons, was Editor. The systematic decrease over the past year in published technical material is illustrated by the following table, giving statistics for each of the four issues and a comparison with the preceding year.

TECHNICAL MATERIAL PUBLISHED IN GEOPHYSICS, 1952–1954

Issue	No. Technical Papers	No. Pages of Technical Papers	Av. Length of Each Paper, p.	No. Pages Other Technical Material	Total No. Technical Pages
July, 1953	12	200	17	20	220
October, 1953	11	183	16.5	15	198
January, 1954	11	152	14	15	167
April, 1954	11	131	12	19	150
Average, Four Issues from April, 1952 to January, 1953	14	213	15	18	231

The only encouraging trend in the figures tabulated above is a consistent decrease in the average number of pages per technical paper in the successive issues. To the extent that this trend represents increased conciseness on the part of our authors, it suggests an improvement which might compensate to a large extent for the decline in the number of printed pages.

The decrease over the past year in the number of papers and in the number of technical pages published in GEOPHYSICS should not in itself be a source of alarm. Quality should always be a more important consideration than quantity. It is difficult, however, to explain such a falling off in the output of publishable material during a year that has seen a record-breaking increase in the Society's membership. With an average membership during the year of about 3,750, the productivity index was 0.196 pages per member for the year. This should be compared with an index of 0.25 for the previous year and 0.29 for the 17 volumes ending in 1952. Both of the latter figures were given by Mr. Lyons in his 1953 Editor's Report.

Since the number of papers presented orally at the Society's regional and annual meetings was at an all-time high during the past year, the fall off in manuscript material does not seem to represent a decline in technical productivity so much as a decline in literary productivity. For example, 68% of the 28 papers presented at the 1952 Annual Meeting at Los Angeles have been submitted as manuscripts for GEOPHYSICS, while only 38% of the 26 presented at the 1953 meeting in Houston were submitted during the following year. In short, it seems more difficult to induce authors of papers presented orally at meetings to write up their material for publication. Letters of solicitation by the Editor have been singularly ineffective, the rate of return (as measured by manuscripts actually re-

ceived) having been only 12.5% during the past year. Perhaps the most effective solution would be the somewhat drastic one of requiring that manuscripts or preprints be submitted for publications before papers will be accepted for oral presentation at meetings. A number of engineering societies have maintained this requirement for many years. One attractive feature of such a system is that it practically assures an over-all improvement in the quality of the papers presented orally at the meetings.

A new set of instructions and suggestions for authors of papers submitted for publication in GEOPHYSICS was printed in the January, 1954 issue of the journal. This was prepared to bring Dr. Nettleton's 1945 instructions up to date and also to set forth specifications on such points of style as capitalization, abbreviations, references, footnotes, etc., so as to achieve greater uniformity of style throughout the journal. The U. S. Geological Survey's standard form for literature citations and bibliographic references has been adopted for GEOPHYSICS, since most of the editors of the leading geological journals have recently agreed to follow this form in the interests of uniformity. The Editor has been much encouraged by the cooperation shown by those authors who have submitted manuscripts since the Style Guide was published. In almost every case they have followed its specifications and suggestions quite closely.

During the past year, work has begun on a revised Cumulative Index of all the Society's Publications, including *Geophysical Case Histories, Vol. 1*. The last index, published in 1947, is out of print and leaves out almost half of the material (measured in number of pages) that the Society has published up to the present. Dr. Kenneth L. Cook, of the University of Utah, has kindly agreed to take charge of this project. Dr. Cook is not only covering material published since the last index was issued but he is also re-indexing all the material covered in the 1947 publication. The final product should have more thorough coverage than the earlier index and should be considerably easier to use. The indexing of technical papers is now virtually complete and the material is being transferred to Flexoprint cards in the Tulsa Business Office for final reproduction by photo-offset. These cards will make it possible for new material to be added at the time it is published. With this system, new editions of the index can be printed more frequently than in the past because there should be no necessity to retype material already published in previous editions. The Cumulative Index should be available for distribution in the summer of 1954. The Editor is most appreciative of the diligence and enthusiasm that Dr. Cook has shown in his handling of this onerous but most important project.

The Editor wishes to express special appreciation to many members of the Society for assistance of various kinds. The Standing Committee on Publications, under the able chairmanship of Dr. John P. Woods, has contributed valuable advice and suggestions on many questions of policy. This Committee's load has been particularly heavy during the past year because of the many decisions necessitated by the reorganization of editorial procedures and the preparation of the Style Guide. The Standing Committee on Reviews, under Dr. Nelson C. Steenland, has continued to furnish the readers of GEOPHYSICS with thorough, well prepared reviews of the world's geophysical literature. Dr. Steenland's willingness to accept a second two-year term as Chairman of this committee deserves particular commendation. Mr. O. F. Ritzmann has continued his faithful service to the Society's membership in preparing his well-selected and well-summarized patent reviews. It is most gratifying to me that this service is being given public recognition at this meeting in the award of a life membership to Mr. Ritzmann. Mr. Roy L. Lay, President of the Society, and the other members of the Executive Committee have been exceptionally cooperative and the Editor wishes to express his appreciation to them for the interest they have taken in the journal and for help of many kinds. Mr. Colin Campbell, Business Manager, has been most diligent in his handling of the Society Round Table and the advertising sections of GEOPHYSICS. During the past year he has taken on additional responsibilities in the handling of the contributor's biographies and pictures and also in the handling of reprint orders. His ever-willing assistance in other aspects of the publishing operation is gratefully acknowledged. The new Associate Editors as previously mentioned, have already made substantial contributions to the efficient and effective handling of a large volume of manuscript material.

In addition, the Editor wishes to thank the following: the technical employees of the Atlantic Refining Company's geophysical laboratories for assistance in reading page proofs; almost fifty

anonymous referees for invaluable aid of a type that, unfortunately, cannot be given public recognition; the Magnolia Petroleum Company for contributing stenographic assistance and other facilities for the editorial work; and Mrs. Margaret Bryson for bearing willingly and efficiently a heavy burden of stenographic work.

With such whole-hearted cooperation from so many sources, the Editor looks forward with pleasure to the second year of his term.

MILTON B. DOBRIN, *Editor*

EXHIBIT E. REPORT ON THE STANDING COMMITTEE ON PROGRAM AND ARRANGEMENTS

Committee appointments supplementing the District Representatives were made and two subcommittees were established—one on Mining Geophysics and one on Revision of a Reflection Quality Map.

Your Vice-President was appointed a Vice-Chairman of the General Arrangements Committee under General Chairman Graham B. Moody. He also served as a member of the Central Committee. SEG was well represented on Convention arrangement committees.

Committee members were very active in securing papers and it was not possible to include all submitted papers on the program. Papers were selected on the basis of quality and diversified interest. Selected papers that had a limited previous presentation before local societies were included in the program.

There was some departure from previous practice in that no technical sessions were scheduled before the formal opening of the meeting on Tuesday, April 14.

Much credit is due members of all three Societies who contributed their service to make this Convention possible. There has been excellent cooperation between the three Societies and the AAPG headquarters staff has contributed in full measure to the perfection of arrangements. Societies members should also know that exhibitors contributed materially to the financial success of this meeting.

KARL DYK, *Chairman*

EXHIBIT F. REPORT OF THE STANDING COMMITTEE ON EDUCATION

The report of the Committee consists solely in the survey of geophysical education for the current scholastic year including the preceding summer session. Thus it differs from the work and the reports of other committees. The report cannot be drawn up in advance because the questionnaires calling for second semester data cannot be filled out by the educational institutions until after the mid-year registration. After they will have been filled out and returned to the business office of the SEG they are forwarded to my office for tabulation and comment. This requires some weeks, so that the report for presentation at the annual meeting and publication in the July number of GEOPHYSICS can scarcely be in the final form until the beginning of April.

JAMES B. MACELWANE, S.J., *Chairman*

EXHIBIT G. REPORT OF THE STANDING COMMITTEE ON DISTINGUISHED LECTURES

The Standing Committee on Distinguished Lectures is as follows:

Paul L. Lyons, Chairman	('54)
Carl Savit	('55)
Peter Dehlinger	('56)
Frances F. Campbell	('57)
John Ferguson	('58)

The Committee secured the services of Dr. Norman Ricker, of the Carter Laboratory in Tulsa, Oklahoma as the fall season lecturer.

Dr. Ricker spoke on "The Wavelet Theory of Seismogram Structure," and completed the following lectures.

November 23, 1953	Ft. Worth Geophysical Society, Ft. Worth, Texas
November 24, 1953	Dallas Geophysical Society, Dallas, Texas
November 30, 1953	Ark-La-Tex Geophysical Society, Shreveport, La.
December 1, 1953	Permian Basin Geophysical Society, Midland, Texas
December 8, 1953	Pacific Section of SEG, Los Angeles, California
December 10, 1953	Canadian Society of Exploration Geophysicists, Calgary, Alberta
December 14, 1953	Montana Geophysical Society, Billings, Mont.
December 15, 1953	Casper Geophysical Society, Casper, Wyo.
December 17, 1953	Dakota Geophysical Society, Bismarck, N. Dak.
December 21, 1953	Oklahoma City Geophysical Society, Oklahoma City, Okla.
January 11, 1954	Denver Geophysical Society, Denver, Colo.
January 21, 1954	Houston Section of SEG, Houston, Texas
January 28, 1954	Geophysical Society of Tulsa, Tulsa, Okla.
March 15, 1954	Southeastern Geophysical Society, New Orleans, La.

Dr. Ricker thus made fourteen formal lectures, and reports show that they were extremely well received.

At the present time, plans are being completed for the lecture tour of Dr. Fred Bullard, of the University of Texas, who will speak jointly to AAPG and SEG societies on "A Volcanic Cycle as Exhibited by Italian Volcanoes" during April and May of 1954. The present schedule of SEG sections is as follows.

April 5, 1954	Ft. Worth Geophysical Society, Ft. Worth, Texas Ft. Worth Geological Society
April 6, 1954	Ark-La-Tex Geophysical Society, Shreveport, La. Shreveport Geological Society
April 19, 1954	Geophysical Society of Tulsa, Tulsa, Okla. Tulsa Geological Society
April 21, 1954	Dallas Geophysical Society, Dallas, Texas Dallas Geological Society
April 26, 1954	Oklahoma City Geophysical Society, Oklahoma City, Okla. Oklahoma City Geological Society
April 30, 1954	Pittsburgh Geophysical Society, Pittsburgh, Penna. Pittsburgh Geological Society
May 4, 1954	Canadian Society of Exploration Geophysicists, Calgary Alberta Alberta Geological Society
May 5, 1954	Montana Geophysical Society, Billings, Mont. Billings Geological Society
May 7, 1954	Denver Geophysical Society, Denver, Colo. Rocky Mountain Association of Geologists
May 10, 1954	North Dakota Geophysical Society, Bismarck, N. Dak. North Dakota Geological Society
May 12, 1954	Northern Section, Pacific Coast Section, SEG San Joaquin Geological Society, Bakersfield, Calif.
May 13, 1954	Pacific Coast Section, SEG, Los Angeles, Calif. Pacific Coast Section, AAPG
May —	Permian Basin Geophysical Society, Midland, Texas West Texas Geological Society
May —	South Texas Geophysical Society, San Antonio, Texas San Antonio Geological Society

Dr. Bullard will thus make fourteen lectures to SEG sections.

The committee has therefore arranged for a total of twenty-eight lectures during the 1953–54 season.

Charges for the lectures have followed the following schedule for Dr. Ricker. It is expected that charges for Dr. Bullard will be reduced from this schedule at least 50% because of dual participation.

Membership of Section	Charges
50 or less	$ 1.00 per member
50–100	$ 50.00
101–200	$100.00
201–300	$125.00
300 and over	$150.00

Experience with this charge schedule, established as precedent by past committees, indicates that it affords a break-even financing and should be continued.

The advice and help of Dr. Milton Dobrin, past chairman, has been greatly appreciated by the committee. The committee greatly appreciates the work of Mr. Edward W. Scott, chairman of the AAPG Distinguished Lectures Committee, in coordinating and arranging the tour of Dr. Fred Bullard. Dr. Peter Dehlinger, committee member, has made a great number of university contacts which should prove very useful for future seasons. A permanent file of contacts and procedures has been established by the committee.

PAUL L. LYONS, *Chairman*

EXHIBIT H. REPORT OF THE STANDING COMMITTEE ON RADIO FACILITIES

ROSTER AS OF 1952–53

Chairman—R. D. Wyckoff
Vice-Chairman—W. M. Rust, Jr.—Houston District

Bart Sorge—California District
E. M. Shook—Dallas District
C. B. Bazzoni—Eastern District
George Belt—Ft. Worth District
Daniel Silverman—Tulsa District
Richard Brewer—Shreveport District
J. O. Parr—San Antonio District

The Committee has had no official business to handle during the 1953–54 fiscal year. The agenda was cleared during the previous year and your committee feels that the current inactivity reflects a very satisfactory state of affairs in the matter of frequency allocations for geophysical use.

We have an indirect but active interest in the work of committees within our associated American Petroleum Institute Radio Facilities Committee and the NPRFCA. In particular, the geophysical industry should be aware of the move toward 20 kc instead of 40 kc channels in the Petroleum Service frequencies above 25 mc. This trend appears to be the only solution to the extreme congestion in the general petroleum service. If the narrow-channel allocation is formally adopted by the FCC at some future date, it will inevitably involve the geophysical channels above 25 mc. where we have secondary sharing rights in certain portions of the 30 mc, 153 mc, and 158 mc bands.

The perennial question of extending Shoran frequency permits in the 230–310 mc. band arose as usual. However, since the channels for handling this matter have been made clear, the operators concerned consult directly with our Washington representative, Mr. Keller, for action. Through his good representations to the Chiefs of Staff, the Shoran permits were again renewed until June 30, 1954.

The Joint Communications-Electronics Committee of the Joint Chiefs of Staff have reiterated that the expansion of military facilities in the 225–400 mc band will be such that interference may be

experienced and therefore the strong possibility exists that the above authorization may be withdrawn prior to June 30, 1954.

Your committee again calls attention to the fact that microwave bands are available for industrial radiolocation use. Thus the problem of securing permits for the use of war-surplus Shoran equipment is now beyond the scope of your committee's activity. However, as already mentioned, effective channels of procedure have been set up whereby individual operators may petition the military for special permits.

While the docket of your committee is now clear, and we are unaware of immediately pending activity, attention is again called to the desirability of maintaining the membership of the Regional Subcommittees so that any required action may be handled without delay.

R. D. WYCKOFF, *Chairman*
W. M. RUST, JR., *Vice-Chairman*

March 9, 1954

EXHIBIT I. REPORT OF THE STANDING COMMITTEE ON MEMBERSHIP

The Standing Committee on Membership for the term 1953–54 was composed of Carl L. Bryan, Chairman, Francis F. Campbell, and J. E. McGee.

Reflecting the growth of the profession, and in no small part the membership campaign conducted in 1952 by the preceding Membership Committee, the Society experienced an outstanding expansion in membership. Tables I and II below show an analysis of this recent growth of the Society.

TABLE I

SEG MEMBERSHIP 1950–1953

	1950	*1951*	*1952*	*1953*	*Increase in 1953*
Honorary	4	4	5	5	0
Active	1,674	1,829	2,058	2,492	434
Associate	603	740	1,008	1,381	373
Student	285	263	295	261	−34
Total	2,566	2,836	3,366	4,139	773
Increase over preceding year	227	270	530	773	

TABLE II

CHANGES IN SEG MEMBERSHIP—1953

	Honorary	*Active*	*Associate*	*Student*	*Total*
December 31, 1952	5	2,058	1,008	295	3,366
Elected	0	456	527	61	1,044
Dropped	0	− 17	− 16	−10	− 43
Transferred to higher grade	0	0	−137	−85	−222
Deaths	0	− 5	− 1	0	− 7
December 31, 1953	0	2,492	1,381	261	4,138

Forty-one members were dropped for failure to pay dues and two resigned. A substantial increase in number of Student members transferred to a higher grade of membership was a contributing factor in the decrease of Student members during the year. Information reached the Society prior to Decem- 31, 1953, of the deaths of the following six Active members and one Associate member which are noted with regret:

Norman J. Highfield
Bertram Wolfram, Jr.
Monroe G. Cheney
William Neal Hostetter
Elmer H. Finch
Earle W. Johnson
Louis A. Scholl, Jr.

The Committee conducted campaigns to locate members whose addresses of record are no longer applicable, to restore good standing relationship with members delinquent in dues and to elect former student members to a higher grade of membership. The principal effort in these campaigns was initiated at the beginning of 1954, and there has not been enough time to produce conclusive results. Early progress, however, in all campaigns has been encouraging.

The Membership Committee recommends to the Society that it provide means for a member to pay his dues in a lump sum which will free him of any dues payment obligation for life. Details of this recommendation have been submitted to the Executive Committee.

CARL L. BRYAN, *Chairman*

EXHIBIT J. REPORT ON THE STANDING COMMITTEE ON HONORS AND AWARDS

During the year 1953–54 the composition of the Standing Committee on Honors and Awards was—

Norman Ricker, Chairman	('54)
L. L. Nettleton	('55)
Andrew Gilmour	('56)
George E. Wagoner	('57)
Sigmund Hammer	('58)

A definite plan of voting for the Best Paper Award was set up which plan proved to be effective in arriving at a decision, while at the same time allowing each member of the committee complete freedom of choice and action. A total of twelve papers were named on the first ballot, while on the second ballot the winning paper received 75 of the 100 votes total. This was especially encouraging in view of the large number of excellent papers which appeared in GEOPHYSICS during the year 1953. The Best Paper Award was recommended for Dr. Charles B. Officer, Jr., for his paper in the October issue entitled "The Refraction Arrival in Water Covered Areas."

A special Life Membership in the society was recommended for Mr. O. F. Ritzmann in recognition of his substantial service over many years in providing material for the Patent section of GEOPHYSICS.

No Honorary Membership was recommended this year.

NORMAN RICKER, *Chairman*

EXHIBIT K. REPORT OF THE STANDING COMMITTEE ON REVIEWS

The Reviews Committee appointed in 1952 by the Executive Committee has completed its first of two years of service. During this year reviews were prepared for four issues of GEOPHYSICS including July, and October, 1953, January and April, 1954. The members, in addition to the Chairman, consist of W. T. Born, Thomas A. Elkins, Richard A. Geyer, E. A. Leonardon, F. A. Van Melle, Paul C. Wuenschel, and W. Jacque Yost. In addition, guest reviews were prepared by L. L. Nettleton, Frederick Romberg, Frank Press, Ivan Tolstoy, L. H. Bailey, Kenneth L. Cook, W. L. Roever, Eugene Usdin, C. Meade Patterson, L. Y. Faust, and Jack Oliver. The cooperation of guest reviewers is especially appreciated.

The number of reviews according to the subject matter is 12 on seismic subjects, 4 gravity, 3 magnetics, 6 radioactivity, 2 electrical, 8 geology, 5 general geophysics, and there was one each on sonic methods and on meteorology.

The Committee Chairman has received one suggestion which should be brought to the attention of the Executive Committee. This is a request that the reviews be indexed yearly in the same manner that the technical papers are indexed. Although this request was only specifically made by one person, namely, Dr. L. L. Nettleton, the possibility has been discussed with the Chairman by several members of the Society.

The Chairman is sincerely grateful for this opportunity to express his thankfulness to the members of the Committee. Dr. Dobrin, the Editor, is to be especially commended for his interest in the affairs of the Committee and for his complete support. The Business Manager, Colin Campbell, is also to be thanked for his wholehearted cooperation and for his conscientiousness in sending the many

publications to the Chairman. Lastly, the publisher of GEOPHYSICS is to be commended for his accurate and attractive handling of the Reviews Section.

NELSON C. STEENLAND, *Chairman*

EXHIBIT L. REPORT OF THE STANDING COMMITTEE ON PUBLIC RELATIONS

The Standing Committee on Public Relations is pleased to report that the success of its major project is assured. For the past year, the entire effort of the Committee has been directed toward the completion of a vocational guidance booklet entitled *Careers in Exploration Geophysics.*

A rough copy and a proposed layout of a sixteen page booklet were presented to the Executive Committee at the 1953 annual meeting. The Executive Committee approved the project in principle and directed the Committee to complete the booklet, to submit a financial plan, and to print 2,500 copies for distribution to the exploration industry. It was further contemplated that orders for copies of the booklet would be solicited from industry. If the exploration industry supported the project, a sufficient number of copies would be printed to fill these orders as well as to provide a sufficient quantity for SEG to distribute a copy to each of the approximately 25,000 high schools in the United States and Canada.

The above has been a time-consuming undertaking and the results to date could not have been achieved without the excellent cooperation of many individuals. SEG student sections and educational institutions offered many valuable suggestions regarding the contents of the booklet. Following the incorporation of these ideas, a revised draft was submitted to a group of high school students in an attempt to evaluate the probable success of the booklet. Following this, the final layout and copy were completed.

In December, 1953, 2,500 copies of *Careers in Exploration Geophysics* were printed and distributed to the exploration industry. Orders were solicited from industry at the following prices:

Prices: F.O.B. Dallas, Texas

1 to 499 copies	65 cents each
500 to 999 copies	60 cents each
1,000 to 1,999 copies	55 cents each
2,000 or more copies	50 cents each

On March 29, 1954, 65 orders and donations had been received in the amount of $10,118.45. It appears that even if additional orders are not received, the Society will be in a position to print at least 50,000 copies of the booklet and to defray the direct mailing costs in sending a copy to each high school in the United States and Canada.

It is impossible for the Committee to express appreciation to each of the individuals who have contributed to this important project. The Executive Committee and the Business Office of SEG have given valuable advice and wholehearted support. The completed booklet contains many contributions from students, educators, and exploration geophysicists. Finally, the project could not have been completed without the fine cooperation and financial assistance of the exploration industry.

R. C. DUNLAP, JR., *Chairman*

EXHIBIT M. REPORT OF THE STANDING COMMITTEE ON PUBLICATIONS

The members of the Committee on Publications are Cecil H. Green, Sigmund Hammer, M. K. Hubbert, L. L. Nettleton, and J. P. Woods, chairman. This committee has the duty of advising the editor of GEOPHYSICS on matters of policy.

Dr. Milton B. Dobrin, Editor of GEOPHYSICS, has prepared a "Style Guide for GEOPHYSICS" which should be of great assistance to those writing papers for publication in GEOPHYSICS. Each member of the committee has reviewed this style guide and has made suggestions.

The last report of this committee, published in GEOPHYSICS for July, 1953, discusses the increasing work load of the editor. The committee has now conferred with the editor concerning this matter, and the SEG has decided to appoint an associate editor for each of the following branches of explora-

tion geophysics: gravity, seismic theory and fundamentals, seismic techniques and operations, magnetic prospecting, and electrical prospecting.

At various times, the editor has requested the committee to advise him concerning papers submitted for publication.

The committee has recommended that no technical paper be accepted for publication in GEOPHYSICS which has been published previously or which is not closely concerned with exploration geophysics.

The committee has recently been requested to establish a policy on the Society's "Index of Wells Shot for Velocity."

J. P. WOODS, *Chairman*

EXHIBIT N. REPORT OF THE STANDING COMMITTEE ON GEOPHYSICAL ACTIVITY

Membership of the SEG Standing Committee on Geophysical Activity during 1953, as appointed by President Lay, was the following:

Dr. A. A. Brant
Newmont Exploration, Ltd.
Jerome, Ariz.

Mr. Herbert Hoover, Jr.
United Geophysical Company
Pasadena, Calif.

Professor K. Iida
Institute of Earth Sciences
Nagoya University
Nagoya, Japan

Ing. A. Garcia Rojas
Petroleos Mexicanos
Mexico, D. F.

Mr. Raoul Vajk
Standard Oil Company (N. J.)
New York, N. Y.

Chairman: Dr. Sigmund Hammer
Gulf Research & Development Company
Pittsburgh, Pa.

The Committee was expanded in size during the year from four members to six to facilitate world-wide coverage in recognition of the increasing tempo of exploration outside the U. S.

The retirement of Dr. E. A. Eckhardt as chairman of the Geophysical Activity Committee during the year marks a milestone in the history of the Committee and of the SEG. The Annual Survey of Geophysical Activity was initiated by Dr. Eckhardt six years ago and, under his leadership, has won wide recognition among geophysicists and throughout the exploration industry. Dr. Eckhardt's retirement is noted with respectful regret and with public recognition of his important contributions to the advancement of geophysical exploration and to the growing prestige of the SEG.

Geophysical exploration for oil on a world-wide scale continued in 1953 at approximately the same level of activity as in 1952. Increases in foreign explorations offset small but definite decreases in seismic operations in the U. S. and Canada. For the first time fair coverage was achieved of magnetic activities, including interpretation of aeromagnetic data. Mining geophysics set new records both in level of field activity and in financial investment. Although there is still room for improvement, the excellent cooperation of many organizations in reporting their geophysical activities to the Committee must be acknowledged.

An analysis of geophysical costs versus over-all exploration costs and their correlation with data on the effectiveness of wildcat drilling emphasizes the need for more and better geophysics to hold down rapidly rising oil-discovery costs. Geophysicists, as members of the exploration team, have a professional responsibility to management and to the public to see that the downward trend in geophysical activity in the U. S. and Canada is reversed promptly and decisively.

SIGMUND HAMMER, *Chairman*

EXHIBIT O. REPORT OF THE STANDING COMMITTEE ON STUDENT MEMBERSHIP

The Student Membership Committee has as its purpose the encouragement of interest among students in geophysics and the Society. Toward this end, the Committee assisted in the organization

of the Houston Student Section of SEG whose membership is composed of students from the University of Houston and the Rice Institute. Membership in this Section is approximately forty students. The Houston Student Section has held monthly meetings throughout the school year with an average attendance of about thirty-five students. In addition, they have completed an ambitious project which consisted of conducting a vertical and surface gravity survey of the Hockley Salt Dome in Hockley, Texas. They are planning another project which will be a water gravity survey of one of the submerged pinnacles some forty miles off the Texas Gulf Coast.

The Texas A & M College at College Station, Texas, and The Pennsylvania State College at State College, Pennsylvania, have expressed an interest in forming student sections of SEG, and it is hoped that these Sections can be organized before the end of the current school year.

Special mention should be made of members of SEG who have addressed various student groups to further their interest in geophysics. Included in this group are outstanding geophysicists who teach geophysics and serve as faculty sponsors in universities and colleges. Other geophysicists have given of their time and talent in making talks before various student groups. An outstanding example of this is the speech made before graduate students in Tulsa by Dr. L. Y. Faust of Amerada on the subject "Some Values Available to Students." This speech is to be published in the April issue of GEOPHYSICS.

EUGENE FROWE, *Chairman*

EXHIBIT P. REPORT OF THE STANDING COMMITTEE ON SAFETY

The committee continued with the previously established program and projects as follows:

1. Accident Information Exchange. There are at present some 40 members of the Exchange and it is felt that a fair cross-section of accident experience of the industry is represented.
2. Safety Posters. About 25 additional posters were added to the catalog making a total of about 75 in all. Most of these were drawn especially for the industry.
   The sale of posters has dropped off appreciably, no doubt due to the fact that no new posters had been recently added. This condition has been alleviated to an extent by the addition of 27 posters that resulted from an industry-wide poster contest conducted by the committee in 1953. A more intensive poster sales campaign is being promulgated at this time.
3. Safety Sessions. As has been the custom in the recent past, the committee formulated a two-hour safety session at the National S.E.G. convention in Houston in March. A similar session was held at the Dallas Regional S.E.G. meeting in November. In addition to special safety sessions, a paper on safety was given at one general session at the National and at two regional meetings.
4. Safety Publications. The committee continued to sponsor two safety promotional periodicals which are made available on a subscription basis at nominal cost to members of the industry.
   These are: "Doodlebuggin' The Safe Way," a bimonthly aimed at the individual and "Exploration Safety Tips," a quarterly intended for supervisors, party chiefs, and safety meeting leaders.
   The committee chairman is co-editor of the latter publication.
5. Following established practice, committee meetings were held at the time of the National meeting in Houston and the Regional meeting in Dallas at which time the various projects of the committee were reviewed objectively and plans were made accordingly.
6. Small Operator Safety Programs. Various members of the committee have assisted small operators in setting up safety programs suitable for their operations.

In addition to the above safety projects during the year, the committee:

1. Developed and produced for sale at cost a Safetygraph especially designed for the industry.
2. Initiated and carried to conclusion a safety poster contest among employees within the industry. From thirty-seven entries, 27 selections were made for the poster catalog. Prizes totaled $175.00.

3. Improved the method of gathering and compilation of accident statistics that allow the computation of accident experience rates. (This project is not the same as the Accident Exchange.) Frequency rates computed from these statistics indicate a material improvement in that rate. Of this, more later.
4. Prepared and mailed out a series of safety promotional letters to owners, managers, or principal officers of geophysical companies, geophysical departments, and shot hole drilling companies.
5. Initiated, in cooperation with the National Safety Council, a Council membership campaign. The ultimate goal here is the establishment of a sub-section for geophysical exploration. Under the prevailing situation of Council membership, with no separate section, the geophysical experience includes other types of exploration, which tends to distort the true facts.
6. Became affiliated with the National Safety Council on Association Membership basis for the purpose of furthering relations between the geophysical industry and the Council.
7. Established and operated a safety exhibit and information booth at the Dallas Regional Meeting in November. A great deal of interest was manifested in this initial exhibit and it is expected to become a permanent part of regional meetings.
8. Recorded, transcribed, and reproduced talks at the November regional session. Copies were made available to the industry at nominal cost.
9. The chairman met with the National Safety Council, Petroleum Section, Executive Committee in their program planning sessions in March 1953 at Corpus Christi and again in May at Galveston. As a result two papers on geophysical safety were presented on the program of the National Safety Congress at Chicago in October.
   The chairman met with the same committee again in February 1954 and is currently at work on a similar program at the forthcoming Congress in October this year.

All expenses incident to the above projects have been defrayed from the safety fund accumulated over the past two years from the sale of posters, publications, etc. A small balance remains in this fund but it likely will not be sufficient to carry on safety activities as extensive as heretofore.

The following statistics point to some measure of success on the part of the Safety Committee's efforts.

	1951	*1952*	*1953*
Frequency Rate.....	53.50*	28.06* -45.7%	18.62† -33.6%

Assuming, for the want of proof to the contrary, that the above figures represent a true picture of the safety experience over the past three years, the 64% reduction in frequency rate in 1953 over that in 1951, evaluated by an accepted formula, would result in a net saving to the industry of the order of

$750,000.00!

The committee has under way the following projects:

1. A 2½-hour safety symposium at the National S.E.G. Meeting in St. Louis in April, the program for which is now complete.
2. A 3-hour safety symposium at the Regional S.E.G. meeting in Houston in May—the program for which is in process.

The committee has under advisement the following projects:

1. Production of a safety film for the industry—specifically the filming of the Bureau of Mines demonstration of the hazards of static electricity in the handling of electric caps. This project

* From A.P.I. reports of 30–35 geophysical contracting companies.
† From SEG Safety Committee statistics project.

would require the outlay of a large sum of money and ways and means of accomplishing this are being explored.

2. Production of a specially designed safety match book to be sold at cost to the industry. This project likewise will require a considerable expenditure of funds not at present available. In view of this fact the project has been shelved temporarily.

The committee is composed of the following original members:

Mr. B. W. Sorge, United Geophysical Company, Pasadena, Calif.
Mr. R. A. Weisbrich, Geotechnical Corporation, Calgary
Mr. W. H. Hawkes, Stanolind Oil and Gas Company, Casper, Wyo.
Mr. Walter Jasper, Shell Oil Company, Midland, Texas
Mr. W. H. Newton, General Geophysical Company, Houston, Texas
Mr. Frank Searcy, Continental Oil Company, Ponca City, Okla.
Mr. John W. Green, Donnally Exploration Company, Lucedale, Miss.

In addition to the above, two new members have recently been added. They are:

Mr. G. M. Kintz, Chief Safety and Health Service, Bureau of Mines, Dallas, Texas
Mr. John Lee, Safety Department, Phillips Petroleum Company, Bartlesville, Okla.

JOHN F. IMLE, *Chairman*

EXHIBIT Q. REPORT OF THE SPECIAL GLOSSARY COMMITTEE

A preliminary version, containing almost one thousand terms, of the SEG's portion of the AGI Earth-Science Glossary was completed during the past year. Copies were distributed to members of the glossary committee as well as members of the Society who were both qualified and interested in using this preliminary version as a guide in offering suggestions for deletions, modifications, or additions to the Glossary. It is hoped that this phase of the work will be concluded by next fall and that the Glossary will be acceptable to the point where a final copy can be submitted to the AGI Committee. In this connection, it is hoped that some member of the Society who has the interest and time will volunteer to accept the responsibility for editing the glossary in final form so that a uniformity and continuity of style can be achieved.

During the past year, at the request of the AGI Glossary chairman, an additional section of the glossary was compiled, covering meteorological terms having specific geologic and geophysical connotations. Dr. Charles C. Bates of the Hydrographic Office of the Navy Department agreed to accept responsibility for the compilation of this phase of the glossary and has recently submitted about seventy terms falling in this category.

The chairman would like to take this opportunity to express his appreciation not only to Dr. Bates but to all the other members of the SEG Glossary Committee, as well as many members of the Society who have contributed so much time and effort on this project. The chairman would like also to acknowledge the excellent cooperation received from the Executive Committee and the Society's Business Manager, Colin C. Campbell, during the past year.

RICHARD A. GEYER, *Chairman*

EXHIBIT R. REPORT OF THE SPECIAL COMMITTEE ON STUDENT ESSAY CONTEST

This report covers the activities of the Committee for 1953. The membership of this Committee is as follows:

Professor John C. Hollister
Colorado School of Mines, Golden, Colo.
Rev. J. B. Macelwane, S.J.
Saint Louis University, St. Louis, Mo.
Mr. E. A. Pielmeier
United Geophysical Company, Pasadena, Calif.

Mr. Fred J. Agnich (Chairman)
Geophysical Service Inc., Dallas, Texas
Dr. M. M. Slotnick
Humble Oil & Refining Company, Houston, Texas
Mr. Hugh M. Thralls
Seismograph Service Corporation, Tulsa, Okla.
Dr. J. Tuzo Wilson
University of Toronto, Toronto, Ontario, Canada

Announcement of the First Annual Student Essay Contest was sent to 52 universities and colleges in September, 1953. In an attempt to ascertain the total number of participants which might be expected to enter the contest, this announcement was followed some months later by a letter to each educational institution originally contacted. A form was incorporated in the letter which was to be completed and returned to the Chairman showing number of participants from each school. Eighteen replies were received from the educational institutions contacted. Only six of the eighteen indicated possible participation in the contest.

The schools which indicated participation are the University of Toronto, California Institute of Technology, Southern Methodist University, Colorado School of Mines, Rensselaer Polytechnic Institute, and University of Wisconsin, with an estimated total of seven students who might enter the contest. However, in the final result there were only two entries.

Although only two manuscripts were received, many of the universities and colleges which indicated no participants this year did remark that they believed the idea of the annual essay contest to be a very good one. Several made the statement that participation from their schools possibly would be forthcoming next year.

The Chairman of the Student Essay Committee wishes to express his appreciation for the cooperation everyone has shown this first year of the contest. Although this initial attempt cannot be considered a success, it is believed that valuable ground work has been laid and considerably more response may be expected next year.

FRED J. AGNICH, *Chairman*

EXHIBIT S. REPORT OF THE SPECIAL COMMITTEE ON BUSINESS OFFICE SURVEY

This committee was appointed by President Lay on April 10, 1953 "to survey conditions in our SEG business office in view of the growth of the Society during recent years."

After investigation the committee recommended increasing the Business Manager's staff to three full-time employes and recommended removal of the business office to larger and more suitable quarters. A survey of available office space was made and suitable facilities were located in downtown Tulsa. After Executive Committee approval, the business office was moved to its new location at 627 South Cheyenne, and additional office furniture was purchased.

The Executive Committee also approved increasing the Business Manager's staff to three full-time assistants, which the Business Manager has done.

The committee also assisted the Secretary-Treasurer in a preliminary survey of business office efficiency.

KARL DYK, *Chairman*

EXHIBIT T. REPORT OF THE GEOPHYSICAL CASE HISTORIES COMMITTEE—VOLUME II

I have the following to report on the progress on the work of the Committee for Geophysical Case Histories Volume II. Forty-eight letters were sent out asking individuals to serve on the Committee. There have been twenty-six acceptances, ten refusals, and twelve who have not as yet responded to the invitation. Undoubtedly the list of those asked to become members of the Committee will grow as situations arise that certain individuals should be invited to become members of the Committee because they appear to be likely sources of case history papers.

In discussing the situation with Paul Lyons in Tulsa, he is apparently satisfied with the project, as far as it has gone, although he reports he has actually received only one completed paper but a number of others have been promised. I also discussed the question of the dead line of March 30th with him and he is of the opinion that we can not meet such a date and that the dead line will eventually have to be set several months later.

If you have any suggestions to offer concerning the program I would appreciate it very much if you would advise me.

Following is a list showing individuals who have been sent letters broken down into "Acceptances," "Refusals," and "Those that have not responded as yet."

COMMITTEE LETTERS SENT TO FOLLOWING

Acceptances		*Refusals*	*Those that Have Not Responded as Yet*
Peterson, R. A.	Dresbach, Chas. H.	Bazzoni, Chas. B.	
Christie, Norman J.	Bradley, R. M.	Ledingham, G. W.	Born, Wm. T.
Dobrin, M. B.	Matjasic, W. L.	Ittner, Frank	Bible, Jno. L.
Harkins, T. L.	Bryan, A. B.	Dyk, Karl	Bemis, H. C.
Romberg, M.	Konkel, P. M.	Pollard, J. C.	Long, G. J.
Newton, W. W.	Von Croy, Stefan	Mathews, J. W.	Locke, E. R.
Clifford, O. C.	Nash, Paul E.	Brant, A. A.	Davis, D. M.
Walling, Dean	Eby, J. Brian	Brown, Hart	Hintze, A. J.
Beers, R. F.	Sherar, E. S.	Hoover, J. W.	Hardy, W. W.
Goldstone, Frank	Nettleton, L. L.	McCann, K. G.	Cummings, Jorge
Wilson, Jno. H.	Frowe, Eugene		Harris, J. A.
Daly, Jno. W.	McCarver, H. C.		Weingartner, Russell
Hammer, Sigmund	Lay, Roy L.		Ellis, L. G.
Fenwick, W. H.			

D. P. CARLTON, *Chairman*

EXHIBIT U. REPORT OF THE CONSTITUTION AND BYLAWS COMMITTEE

The major activity of the Constitution and Bylaws Committee the past year has been the recommendation of amendments to the Bylaws needed as a result of the decision to hold the Annual Meeting of the SEG in the fall.

The proposed Constitutions and Bylaws of the Casper Geophysical Society, the Houston Student Section of SEG, the Geophysical Society of South Texas, the Southeastern Geophysical Society, and the Montana Geophysical Society have been reviewed.

W. M. RUST, JR., *Chairman*

EXHIBIT V. REPORT OF THE ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION

The full Committee has held three meetings, in Dallas October, 1952, in Denver May, 1953 and in Denver November 17, 1953. Dr. Roland F. Beers, a new member, attended the last meeting.

Two meetings will be held per year, both probably at Denver.

The Committee believes its most important function is to encourage examination of seismic shotholes for radioactive minerals, especially in the general areas where such minerals have been or may be found.

It is noteworthy that lowering of a radioactive probe in shot holes is far superior to later examination of cuttings at the surface.

Four Information Circulars have been distributed to Committee members, and to others who apply to the Chairman, Dr. Fred H. Lahee, c/o Sun Oil Company, Box 2880, Dallas, Texas. These circulars contain information of considerable interest to all who are now seeking or may in the future seek radioactive minerals.

HENRY C. CORTES, *Vice-Chairman*

EXHIBIT W. REPORT OF AMERICAN GEOLOGICAL INSTITUTE DIRECTOR

I attended the meeting of the Board of Directors of A.G.I. in Toronto as director from the Society of Exploration Geophysicists Monday, November 9.

In the two years during which I have had the honor of representing the society as director of A.G.I. I have attended three meetings of the Board. At the first two meetings I was impressed by the futility of effort of A.G.I. It had apparently been formed principally to compile a roster of scientific men engaged in earth science. When the war ended its executive committee began to scratch around for some reason to keep it going, but neither the A.G.I. nor its first two executive directors had any idea where it was going. And the projects it embarked on—road maps, propaganda booklets to induce students to enter the "Earth Science" professions, even the glossary—overlapped projects of the constituent societies. There was, as you know, serious doubt last spring as to whether or why A.G.I. should survive.

At the meeting in Toronto last Monday I came to the conclusion that with Mr. Hunt, the new executive director, in charge it may head toward fulfilling its (in my opinion) proper function; that is, co-ordination of the activities and projects of the constituent societies. The roster of scientific men has to be brought up to date. Congress is pushing the Manpower Commission on this. A.G.I. will send out and receive the questionnaires but Mr. Hunt is trying to have the A.A.P.G. take over this work. The A.A.P.G. files already contain 10,000 of the 20,000 names likely to be on this roster. A.G.I. would turn over to A.A.P.G. the grant ($11,500.00) received from the Manpower Commission for this project. It would still be an A.G.I. project being done by a member society equipped to do the job. The abstracting of papers on geology would be turned over to G.S.A. In the not too distant future this project is likely to be self-supporting. The glossary will be put out in parts by the various societies interested and may be compiled as a unit. All this conforms with the resolution passed at Toronto that "in the interest of economy and efficiency, it be the policy of the A.G.I. to utilize the established facilities of the business offices of the member societies *to the extent practicable.*" The A.G.I. is in a position to obtain grants from the Manpower Commission, the National Academy of Science, etc., which no single society would be able to obtain, and to work on projects of common interest.

Under the new setup I believe the A.G.I. merits and should receive our continued financial support.

At Toronto the board received the various routine reports and made changes, almost entirely clarifications, of the Constitution and Bylaws of the Institute.

New officers were elected:

C. R. Longwell, President
E. A. Eckhardt, Vice President
P. E. Cloud, Jr., Secretary-Treasurer

We know that, as Dr. Eckhardt said, if hard work and devotion will make A.G.I. go, we can depend on him.

I should like to reiterate my recommendation that our society continue to support A.G.I. until we find whether the new arrangement works out. I believe there is a place for it as coordinator of the activities and projects of the member societies.

ANDREW GILMOUR

EXHIBIT X. REPORT OF NATIONAL RESEARCH COUNCIL REPRESENTATIVE

Since the 1953 report (GEOPHYSICS, Vol. XVIII, No. 3, July, 1953, page 760) the name of this unit of the National Research Council has been changed from "Division of Geology and Geography" to "Division of Earth Sciences" to more clearly indicate the scope of its activities. The member societies of the Division and the fields of the other 7 Divisions were listed in the 1952 report.

Your member was not able to attend the annual meeting of the Division in Washington on May 1 and 2, 1953. From the annual report of the Division and subsequent reports received, the activities

of the Division during the past year, which may be of interest to members of the Society of Exploration Geophysicists, were as follows:

(1) The administration of the Division has been changed. The Chairman will now serve for one year instead of three as formerly. The administration will be by the Chairman, the past Chairman and two Vice Chairmen, one of whom will serve as Chairman for the following year. The Chairman for the 1953–1954 year is Dr. Francis Birch, of Harvard University. Dr. Ernst Cloos, of Johns Hopkins University, is past Chairman. Vice Chairman and Chairman designate is Richard J. Russell, of Louisiana State University. The Division now has a full time Executive Secretary in the person of H. R. Gault (on leave from Lehigh University) instead of one person sharing his time between this position and a similar function for the American Geological Institute. (The A.G.I. also has a full time Executive Secretary, Charles B. Hunt.)

(2) The principal activities of the Division throughout the year, between its annual meeting, are those of its various committees. In addition to the executive and certain advisory committees the following technical committees are active: Chemical Composition of Sediments; Clay Minerals; Geography, Advisory to Office of Naval Research; Construction and Use of Precise Globes; Map Sketching from Aerial Photographs; Measurement of Geologic Time; Paleobotany; Review Articles in Geology and Geophysics; Stratigraphy and Topographic Maps Illustrating Cultural Geography; and Treatise on Marine Ecology and Paleoecology. These have been active in varying degrees as indicated by the individual committee reports in the annual report.

A committee of special interest to SEG is that on Geophysics, Advisory to the Office of Naval Research (which is a joint committee with the Division of Physical Sciences). SEG members recently or currently on this committee are E. A. Eckhart, L. B. Slichter, Darrell S. Hughes and James T. Wilson.

The last annual meeting included a conference on "Our Water Resources." This included prepared discussions on: water availability, need and disposal; problems of management and administration relating to water reuse; water research problems in California; water problems in the high plains; stream flow, water availability and sedimentation in arid regions; Gulf Coastal water; western water law; ground water; and water from the viewpoint of an economic geographer. Some 70 scientists attended and 24 are listed as participants in the discussion. Several of these are SEG members.

L. L. NETTLETON

EXHIBIT Y. REPORT OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE REPRESENTATIVE

ABRIDGED REPORT OF THE MINUTES OF THE MEETING OF THE COUNCIL OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

BOSTON, MASSACHUSETTS, DEC. 27, 30, 1953

The Council convened at 4 P.M., December 27 and 9 A.M., December 30. President Edward U. Condon presided at both sessions. The attendance at these sessions was 118 and 112 respectively.

Announcement was made of the appointment and acceptance of three officers to replace the current incumbents who had resigned.

Administrative Secretary: Dr. Dael Wolfle, currently director of the Commission on Human Resources and Advanced Training.

Editor: Dr. Duane Roller, formerly Assistant Director of Research, Hughes Research and Development Laboratory, California; founder and former editor of the *American Journal of Physics.*

Treasurer: Dr. Paul A. Scherer, Executive Officer, Carnegie Institution of Washington.

Dr. George W. Beadle, Professor of Biology and Chairman of the Division of Biology, California Institute of Technology, was elected President-elect by unanimous vote after three ballots.

Announcement was made of the nomination of 16 vice presidents and chairmen of sections of the A.A.A.S., all of whom were duly elected by unanimous vote.

Dr. Wallace W. Atwood, Jr. of the National Academy of Sciences, is vice president and chairman of Section E, Geology and Geography.

Dr. Wallace R. Brode of the National Bureau of Standards and Dr. Thomas Park of the University of Chicago, were unanimously elected for full terms of four years to fill vacancies on the Board of Directors.

Attention was called to the increase in the number of associated and affiliated societies during the year which now amount to 154 affiliated societies, 53 associated societies, and 42 affiliated academies of science, a grand total of 249 organizations.

Commendation and appreciation were voted for the special service to the editorial board by Drs. Bentley Glass, William L. Straus, and Miss Ruth Christman. It was voted unanimously that special tribute be paid to Dr. Howard Meyerhoff, former Administrative Secretary and Mrs. Gladys M. Keener, former Editor, for their devoted services prior to the termination of their work for the Association.

Former minutes were unanimously adopted in remembrance of Dr. Robert A. Millikan, president of the association in 1929, who died December 19, 1953, and in remembrance of Edwin G. Conklin, president of the association in 1936, who died late in 1952.

The report of the chairman of the board was presented by Dr. Detlev W. Bronk. Some of the highlights of Dr. Bronk's report follow:

a. The desirability of a new headquarters building.
b. Publication of two symposium volumes and the preparation of four now in press.
c. Microcard edition of *Science*.
d. The problem of a biographical directory of American scientists and the appointment of an advisory committee to the publisher.
e. Establishment of a third center for the Gordon Research Conferences.
f. Note that the present continuing gain in membership is slight.
g. Schedule of future meetings:

1954 Berkeley, California
1955 Atlanta, Georgia
1956 New York City
1957 Indianapolis, Indiana
1958 Washington, D. C.

Financial report showed increase of $100,000. in the assets of the association during fiscal 1952.

It was noted that a committee had been appointed to examine the operation of the association under the present constitution and by-laws.

Upon reading of the statement by Dr. R. E. Blackwelder it was unanimously moved that the council affirm the prepared statement outlining the responsibilities of the administrative secretary in conducting the operation of the association.

Resolution prepared by a committee under the leadership of Dr. Paul E. Klopsteg was unanimously passed as follows:

"RESOLVED: That the Council of the American Association for the Advancement of Science, assembled at Boston on the occasion of its 120th meeting, expresses its approval and commendation of the proposal by President Eisenhower before the United Nations for international cooperation towards the beneficial utilization of nuclear energy. Many scientific and technical problems remain to be solved in such an undertaking. Scientists throughout the world will welcome the opportunity to work together on these problems as a service in the interest of peace and a contribution to the welfare of all peoples. Science is a major constructive force in the world. It knows no geographical bounaries. Hence the prospect of bringing scientists from many countries together in a collaborative research and development effort in this promising area

provides great hope not only for immeasurable material benefits but especially for better understanding and goodwill among nations."

Recognition of services of distinguished guests and council members was given by appropriate resolutions.

The question of equal hotel accommodations for all members of the association was discussed in some detail. The acting administrative secretary, Dr. Raymond L. Taylor, made extensive remarks which gave considerable assurance to the body that all members would find adequate facilities at future meetings of the association.

A regional meeting of the Society of Exploration Geophysicists was held at the Hotel Somerset, Boston, Massachusetts, December 29, 1953, as an affiliated society of the American Association for the Advancement of Science in its 120th Annual Meeting. The appointed chairman of the meeting was Professor L. Don Leet, Chairman of the Division of Geological Sciences, Harvard University. The Committee in charge of the program consisted of Dr. R. B. Ross, Chairman and Dr. Frank Press. Dr. R. F. Beers represented the Society of Exploration Geophysicists on the Council of the American Association for the Advancement of Science.

As a result of the effective activity of the program committee, several excellent papers were presented to the Society in two sessions. Dr. Francis Birch of Harvard, Massachusetts, Department of Geology, served as chairman of the morning session, and Dr. R. F. Beers presided during the afternoon. A list of the papers and their authors is given below.

Attendance numbered 37 at each of the two sessions. This expression of interest was considered well worth the effort in organizing the meeting, particularly in view of the large number of distracting interests offered by the A.A.A.S. meetings. It was observed that better attendance at future regional S.E.G. meetings in connection with A.A.A.S. would undoubtedly result from more thorough coordination with other groups of the association. As a first effort these results are encouraging to the representatives of the society who recommend following the precedent by holding a regional meeting at the 1954 A.A.A.S. Annual Meeting in Berkeley, California, December 26–31.

Undoubtedly some of the papers offered at the Boston meeting will be submitted for presentation at the Annual Meeting of the Society in St. Louis, April 12–15, 1954. Others will be submitted to the Editor of GEOPHYSICS to be considered for publication in future issues. The significance of the papers was generally above average. Special attention was given to recent geophysical developments in New Brunswick as related by S. H. Ward of McPhar Geophysics Limited, Toronto. Other papers of interest were those by Professor John E. Riddell of McGill University, Dr. J. R. Balsley of the United States Geological Survey, and a fundamental paper by Dr. B. F. Howell, Jr. of the Pennsylvania State College and D. Budenstein of the United States Geological Survey. The program follows:

"The Ionium Method of Age Determination—Recent Developments," by Herbert L. Volchok and J. Laurence Kulp

"Engineering Applications of the Seismic Refraction Method," by Reverend Daniel Linehan, S.J.

"Review of the Development of the Airborne Magnetometer," by Roland F. Beers and Donald E. Burnham

"The Application of Geophysical Methods in New Brunswick," by S. H. Ward

"Reconnaissance Geochemical Surveys for Base Metal Mineralization Carried Out in Lemieux Township, Gaspe Peninsula, Quebec," by John E. Riddell

"Iron and Titanium Oxide Minerals of Adirondack Rocks and Their Magnetic Properties," by J. R. Balsley

"A Brief Summary of Three Years of Seismic Field Research," by J. W. Hammond and H. M. Thralls

"Vertical Gravity Gradient in San Jacinto Monument, Texas," by Sigmund Hammer and E. H. Farr

"Evaluation of Linear Operators in Seismograph Analysis," by Enders A. Robinson

OFFICERS FOR THE EIGHTEEN MONTHS ENDING IN OCTOBER, 1955

Left to right: Milton B. Dobrin, Editor; Hugh M. Thralls, Secretary-Treasurer; Paul L. Lyons, President; Roy F. Bennett, Vice-President; Roy L. Lay, Past President.

"Energy Distribution in Explosion-Generated Seismic Pulses," by B. F. Howell, Jr. and D. Budenstein

"Airborne Magnetometer Profile from Portland, Oregon to Albuquerque, New Mexico," by W. B. Agocs, J. C. Rollins and E. Bangs

ROLAND F. BEERS

EXHIBIT Z. REPORT OF THE SPECIAL COMMITTEE ON CODE OF ETHICS

The Special Committee to recommend a Code of Ethics for the S.E.G., consisting of J. A. Brooks, Jr., C. H. Green, and George E. Wagoner, has been organized.

The committee is studying prior attempts to establish a Code of Ethics for the S.E.G. as reflected by the files of the Constitution and By-laws Committee; the history of the ethical code in the A.A.P.G.; the established codes of ethics of other professional societies; and other material which is of assistance in the preparation of a report.

Preliminary suggestions of a concrete nature will be submitted to the Executive Committee as soon as possible and a final report will be prepared before the Annual Meeting in 1955.

J. A. BROOKS, JR., *Chairman*

EXHIBIT AA. REPORT OF THE PERMANENT BUILDING COMMITTEE

The permanent building Committee met in Dallas, March 5, to discuss the feasibility of owning a building to house the business offices of our national Society. All of the members of the Committee were present and with one exception the local sections they represent felt that it would be desirable to own our own building; however, the majority of the Committee voted not to go into the project unless sufficient funds could be raised, prior to the building of a structure, to finance it without obligating the Society to an amount greater than could be amortized by the present rental paid for the space in Tulsa. This is probably equal to saying that the entire amount of the building would have to be raised prior to its construction, since it would cost at least $200 per month to operate a building of the size being considered.

The Committee suggested that the Executive Committee or the Council have the various local sections attempt to raise the necessary funds by direct solicitation of individuals and companies.

The Committee did not decide on the city in which this proposed building should be located but did limit its location to Tulsa, Fort Worth, Dallas or Houston. It is proposed that each of these cities, that so desire, should submit a plan for financing the construction of the building to the Executive Committee, and that the Executive Committee or the Council should make the decision as to which city the permanent building should be located.

T. O. HALL, *Chairman*

FIRST ANNUAL STUDENT ESSAY CONTEST

GERHARD E. LUKK

GERHARD E. LUKK, a graduate of the University of Toronto in the Geophysics Option of the Engineering Physics Course, has been awarded first prize in the first Annual Student Essay Contest of the Society of Exploration Geophysicists. Mr. Lukk was born April 24, 1928 in Tallinn, Estonia. He attended school in Estonia until the year 1944, and completed secondary school in 1947 in the Estonian displaced persons school in Stolzenau.

He entered the University of Toronto, Canada, in the fall of 1950, and was to join the Exploration Division of the Shell Oil Company in Canada upon graduation.

The certificate of award, with a check in the amount of $150.00, was presented by Mr. Fred J. Agnich, Chairman of the Special Committee on Student Essay Contest, at the Annual Joint Meeting in St. Louis, April 13, 1954. The award was received for Mr. Lukk by Rev. J. B. Macelwane, S.J. The prize-winning essay, "The Williston Basin and its Exploration Problems," is published in this issue of GEOPHYSICS on pages 572–581.

AWARD FOR BEST PAPER OF 1953

Dr. Charles B. Officer, Jr. (left) received the certificate and plaque representing the annual Best Paper Award for 1953 from President Roy L. Lay during the opening session of the Annual Joint Meeting, April 13, 1954 in St. Louis. Dr. Officer's paper, "The Refraction Arrival in Water Covered Areas," appeared in the October, 1953 issue of GEOPHYSICS.

SECOND AWARD OF LIFE MEMBERSHIP—CITATION

L. L. NETTLETON

At this time, the Society of Exploration Geophysicists presents an award which is entirely outside its regular program of recognition of special accomplishment. The recipient, Mr. O. F. Ritzmann, is an old-timer in geophysics, having joined the then very new Gulf Research Department in 1929. His previous career was academic, including B.S. and M.S. degrees at Pennsylvania State College, graduate work in Physics at California Institute of Technology, and teaching at Penn State, Michigan School of Mines, and Lehigh.

At Gulf, he began in the development of their first reflection seismograph equipment when there were about three traces on 35 mm paper and was in charge of the seismograph instrument section until 1944 when his increasing interest in patents resulted in his transfer to the patent department of the Gulf Oil Corporation in Washington. For the last year he has been back in Pittsburgh as Patent Engineer.

Mr. Ritzmann has performed a very special service to the Society of Exploration Geophysicists. Since October 1939, our journal, GEOPHYSICS, has carried a Patents section consisting of a classified list, with appropriate brief comments, of the recent patents of interest to the members of the Society. This list has run from a few to as many as 50 pages of closely printed type per issue. The amount of labor and the devotion to the Society represented by this section is much greater than is realized by most of our members. The special recognition being granted at this time is, indeed, well deserved.

Like so many things, the Patents section started in a small way. Originally it was part of a regular operation in the laboratories of the Gulf Research & Development Company, carried out first by Gary Muffly and B. Perkins, Jr., which was generously made available to the Society. When this function was taken over by Mr. Ritzmann in 1942, it was gradually expanded to include the wider interests represented by the members of the S.E.G. The expansion finally had to be curtailed when Ritzmann found himself burdened with patents on the bus, at home, and at all spare times, which were being perused for the benefit of the S.E.G. The Patent section is a very large chore and the Society should

O. F. Ritzmann (right), recipient of the second award of Life Membership, received the certificate from L. L. Nettleton during the opening session of the Annual Joint Meeting, April 13, 1954 at St. Louis.

be grateful for its steady accomplishment. Since being taken over by Mr. Ritzmann, the Patents section totals nearly 600 pages, a much greater volume of material than contributed by any other member of the Society.

It is a pleasure to me to have this opportunity to represent the Society of Exploration Geophysicists by presenting to you, Ritz, this life membership in the Society as a recognition of your service to the Society. May it represent in some small way our appreciation of what you have done for us.

ABSTRACTS OF PAPERS PRESENTED AT THE TWENTY-FOURTH ANNUAL MEETING MUNICIPAL AUDITORIUM, ST. LOUIS, MISSOURI APRIL 12–15, 1954

Extra Dividends from Safety

T. O. HALL, General Geophysical Company, Houston, Texas

The Dollar Value of Safety to the Geophysical Operation

F. F. REYNOLDS, Seismic Exploration Inc., Houston, Texas

Safety Pays Small Business, Too

A. M. BALTZER, National Safety Council, Chicago, Illinois

The Accident Profile

FRED CLAIBORNE, Stanolind Oil and Gas Company, Tulsa, Oklahoma

Geophysical Accident Facts

B. W. SORGE, United Geophysical Company, Pasadena, California

Mamou Field—A Case History

D. RAY DOBYNS and W. B. ROPER, Magnolia Petroleum Company, Dallas, Texas

This paper presents the geological and geophysical investigations leading to the discovery of the Mamou Oil Field. Gravity, seismic, and subsurface maps, cross sections, and production data will be presented.

Improvement of Seismic Data by Computing Procedures

ROLAND F. BEERS AND CLIFFORD F. CASEY, Beers and Heroy, Troy, New York

A simple transcribing device is used to place conventional seismic records on magnetic tape. In this form studies have been made of various computing procedures to determine their effect on signal-to-noise ratio. The observed improvements may also be accomplished in direct recording of seismic data on paper or magnetic tape.

Correlation Analysis of Seismic Exploration Data

HAL J. JONES AND JOHN A. MORRISON, Texas Instruments Incorporated, Dallas, Texas

Correlation analysis techniques may be applied to seismic data already subjected to standard recording and analysis procedure in an effort to extract additional information. These techniques involve determination of certain parameters which provide a quantitative measure of the correlation between two sets of data. Among the most useful of these parameters are the auto- and cross-correlation coefficients and functions long used by statisticians in time series analysis and recently applied to filtering and prediction problems in the field of communications. This paper discusses some applications of correlation analysis in interpretation of seismograms. The use of auto-correlation to identify

repetitive patterns on complex seismograms is described. Examples of the determination of the power spectrum from the auto-correlation function are presented. The use of cross-correlation analysis to identify weak messages masked by high noise is illustrated for several problems. Equivalence of correlation analysis procedures to filtering operations is stressed. Special analog computing equipment facilitating computation of correlation coefficients and power spectra directly from oscillograms or graphs is described.

Energy Distribution in Explosion-Generated Seismic Pulses

B. F. Howell, Jr., The Pennsylvania State University, State College, Pennsylvania and D. Budenstein, United States Geological Survey

Three separate pulses were recognized on a group of seismograms of ground motion resulting from explosions measured at distances ranging from 10 to 1,172 feet from the shot point. It is believed that the first pulse represents primarily body waves, the second pulse coupled waves formed by internal reflections in the low-velocity surface layer, and the third pulse Rayleigh and Love waves arriving simultaneously. The ratios of the energies of the various pulses are given for several distances. The rates of attenuation of the three pulses are expressed as exponential functions and also as inverse power functions.

Recording of Seismic Waves in Bore Holes

E. T. Howes, United Geophysical Company, Pasadena, California

Reflected and refracted seismic waves are normally detected by a "Horizontal Spread" of geophones placed at the surface of the ground. However, these same seismic waves can be detected by a "Vertical Spread" of geophones suspended in a fluid-filled bore hole. Equipment specially designed for use as a vertical spread in shallow bore holes is described in this paper.

Sample records taken under various field conditions are shown. The relative advantages and operating problems are also discussed.

Geophysical Activity in 1953

Sigmund Hammer, Gulf Research and Development Company, Pittsburgh, Pennsylvania

Report of Chairman S.E.G. Standing Committee on Annual Review of Geophysical Activity.

Using Geophysics in Vatican City

Daniel Linehan, S.J., Weston Observatory, Weston, Massachusetts

The present paper explains the employing of geophysical methods in directing archeologists where to excavate in their recent studies beneath Saint Peter's Basilica at Vatican City, Rome. For the most part the seismic refraction method was used, but this was also complemented with the electrical resistivity method. The paper is illustrated with Kodachrome slides taken during operations in Vatican City.

The Present State of Geothermal Investigations

Francis Birch, Harvard University, Cambridge, Massachusetts

At present, the emphasis in geothermal studies in non-volcanic areas is on the flow of heat to the surface, a quantity of much theoretical importance. The number of reliable determinations of heat flow is still small, with few of the oil-producing regions represented. While thermal gradients range from about 5 to 70° C/km, most of the measurements of heat flow fall within the range, $1.2 \cdot 10^{-6}$ cal/cm² sec $\pm$ 50%, including the recent values for the deep ocean basins. There are suggestions of regional variations, but many more measurements reliable to 10% or better will be needed for further progress. The study of geological regions or provinces, rather than single localities, is especially

desirable, and should be feasible in areas extensively drilled for oil. The principal requirements which are difficult to meet are (1) approximate thermal equilibrium, which usually requires an undisturbed period of many months, and (2) availability for laboratory study of cores representing the major formations pentrated by the well. A renewal of interest in this subject among oil geologists, with recognition and exploitation of opportunities as they arise, could greatly advance its development.

A Seismic Reflection Quality Map of North America

PAUL L. LYONS, Anchor Petroleum Company, Tulsa, Oklahoma

A reflection quality map of North America has been prepared by a subcommittee of the Program and Arrangements Committee for 1953–54. The map brings to date the map of the United States prepared for the April meeting of the SEG in 1951, and the remainder of the continent has been added. The map designates as good, fair, or poor to NG all sedimentary areas of the continent in respect to reflection quality in conventional seismic explorations. A ready correlation is apparent between the areas of intensive oil and gas development and areas of fair to good reflection quality. The rapid oil and gas developments in recent years in western Canada may be directly ascribed to the unexpectedly good seismic data obtained. The committee notes the invasion of the poor to NG areas by the use of special techniques and the reward to be gained by progress in this direction, for approximately half of the sedimentary area of North America yields poor to NG reflections.

Some Problems of Standardization in Recording Seismic Data on Magnetic Tape

ROLAND F. BEERS AND CLIFFORD F. CASEY, Beers and Heroy, Troy, New York

It is believed that eventually a very large amount of seismic data will be recorded directly on magnetic tape. In this form many improvements in signal-to-noise ratio resolution and accuracy may be achieved. While magnetic recording systems are in the early stage of development it may be wise to consider some of the problems which will arise in establishing standards for the equipment and procedures required by the geophysical industry.

This paper recognizes the need for standardization, states some of the current problems and recommends procedures for studies of the problem to be continued. A compilation of existing equipment is included, derived from an illustrated brochure which will be distributed to all who may request it.

Recent Results of the Model Seismology Program at the Lamont Geological Observatory

JACK E. OLIVER, FRANK PRESS, AND MAURICE EWING, Lamont Geological Observatory, Palisades, New York

At the Lamont Geological Observatory elastic wave propagation is investigated by means of pulses of ultrasonic frequencies traveling through small scale models. The use of two dimensional rather than three dimensional models greatly enlarges the scope of investigations. Two dimensional models are cheaper and more readily available, require less space, are easy to fabricate, require less elaborate electronics and have a favorable ratio of compressional to shear velocity. Current applications of the seismic model, or analog computer, to specific problem of surface wave dispersion and reflection and refraction of body waves will be among the topics discussed.

The Duck Lake Field—St. Martin Parish, Louisiana

EDD R. TURNER, JR., Humble Oil and Refining Company, New Orleans, Louisiana

The Duck Lake geologic structure was found sometime before the war by reflection seismograph, and an exploratory well was drilled in the area in 1941 which logged gas shows but was abandoned. The Humble Oil and Refining Company conducted gravity and seismograph surveys in the area after the war the drilled two dry exploratory wells in 1947. The discovery well was completed by Humble in 1949, and since then eighty-four oil and gas wells have been drilled.

The Duck Lake structure is a dome-shaped closure between a large down-to-the-northwest fault which limits production on the north side of the field and a smaller down-to-the-southeast fault which limits but does not completely interrupt oil and gas accumulation on the southern side of the field. This smaller fault dies out "on structure."

Oil and gas accumulations are found in Miocene Age sediments in the *Bigenerina floridana*, *Uvigerina lirettensis*, *Robulus*, *Operculinoides* and *Discorbis* zones. This interval extends from 8,000 feet to almost 13,000 feet. There are recognized fourteen gas sands, six oil sands and seven associated gas and oil sands (total 27). The field gas column is 1693 feet and the oil column is 430 feet.

A geological committee has been working on the field since late in 1950, and the geologic maps shown are taken directly from the committee's work. Presented with this paper are eleven lantern slides and twenty-one kodachrome transparencies. A model of the D-1 gas sand will be displayed also.

Reflection Quality, a Fourth Dimension

BEN F. RUMMERFIELD, Century Geophysisal Corporation, Tulsa, Oklahoma

The quality of seismic reflection results has a direct relation to newer petroleum provinces in the North American Continent. An approach is suggested whereby a local seismic study of changes of physical characteristics of subsurface reflecting horizons can be attempted. The changes in the quality of deeper reflecting horizons in relation to a persistent shallow, or "control," horizon may be able to add a fourth dimension to present seismic interpretations.

A Magnetic Compounder for Directional Discrimination of Seismic Waves.

C. C. LASH, T. H. GILMARTIN, and J. D. EISLER, Stanolind Oil and Gas Company, Tulsa, Oklahoma

The magnetic compounder is a multiple trace magnetic recording and playback device which provides discrimination between seismic waves based on their direction of arrival. The device makes a temporary recording of the signals from twelve groups of seismometers. The continuously moving magnetic tracks carry the signals to a large array of pickup coils before erasing. These coils are connected so as to add their outputs with a systematic pattern of time delays. By this means, the recording is analyzed into components on the basis of movement, i.e., differences in arrival time. The magnetic compounder has been tested with procedures intended to lead to routine field use. Since the device is inherently capable of improving the ratio of reflected energy to the extraneous seismic noise by virtue of its directional sensitivity, the instrument was field tested in various areas to evaluate its capability of resolving dip as well as to carry correlation analysis. The use of the magnetic compounder in research work is illustrated as a method for emphasizing and separating surface waves.

Field Experience with Magnetic Recording of Seismic Data

R. A. PETERSON, United Geophysical Company, Inc., Pasadena, California

Experience gained during two years of field operation with integrated seismograph-magnetic recording equipment is discussed. The information in reflected seismic waves is often distributed over a relatively wide range of frequencies, and there is a basic advantage in making use of as much of this information as possible. Magnetic recording with broad frequency coverage, and flexible play-back procedures provides a practicable means for extracting a maximum amount of information, consistent with the amount of noise present. This can be particularly important in delineating complex geological relationships such as faulting, unconformable surfaces, and so forth, where maximum resolving power is essential. Some examples will be given.

Field recording and play-back procedures, and multiple interpretation techniques for obtaining maximum information are discussed. Some problems and limitations are pointed out.

Magnetic recording in itself does not insure success or solve all problems, but can be a valuable tool if skillfully used.

The Least Squares Approach to the Residual Analysis of Gravity Data

THOMAS J. BEVAN, Consultant, Tulsa, Oklahoma

The primary purpose of residual analysis is to bring out local anomalies of relatively small magnitude that would otherwise be overlooked or under-evaluated because of the "shadowing" of a large regional gradient. It is extremely difficult to draw accurately a graphical estimation of the regional gradient and, at best, it contains considerable human error. By fitting a cubic surface to the regional pattern with a least squares process the residual values can be calculated analytically eliminating these human errors. Control points on the residual map can be made identical with the station control. The method is economical if punched cards and electronic calculators are used.

Examples of results are shown from the Rocky Mountain, Williston Basin, Southern Oklahoma, and Gulf Coast provinces.

Two-Dimensional Smoothing, with Special Reference to Gravity

THOMAS A. ELKINS, Gulf Research and Development Company, Pittsburgh, Pennsylvania

A brief discussion is given of known smoothing methods for one-dimensional data, that is, data along a profile. Next is reviewed the previously published work on smoothing two-dimensional data, that is, data over an area. Methods of two-dimensional smoothing using least squares polynomials are then developed and sets of smoothing coefficients derived for grid figures frequently occurring in practice. The application of these sets to gravity and second derivative values is then studied from the statistical viewpoint. Maps of practical field data before and after smoothing are included as illustrations.

Resistivity Surveys Over Slump Structures, Tri-State Lead-Zinc Mining District, Cherokee County, Kansas

KENNETH L. COOK, U. S. Geological Survey, University of Utah, Salt Lake City, Utah

To test the feasibility of using geophysical methods to detect buried slump structures, which are favorable areas for ore deposition in the Tri-State lead-zinc mining district, the U. S. Geological Survey in cooperation with the U. S. Bureau of Mines made resistivity surveys in the Badger-Peacock area in 1951 and again in 1953. An area of about $3\frac{1}{2}$ square miles lying immediately east of the edge of the Cherokee overlap about 9 miles northwest of Joplin, Missouri was surveyed. About 10,500 resistivity stations were taken over a total traverse distance of about 96 miles, using horizontal resistivity profiling techniques: in addition about 80 vertical resistivity profiles were taken, both with the Lee configuration.

Except for a few scattered small outcrops, the underlying rocks are concealed by overburden. Solution in the Mississippian Boone limestone has resulted in the collapse of the limestone and slumping of the overlying Pennsylvanian Cherokee shale into the openings.

The apparent resistivity of the Boone limestone, which generally lies immediately below the alluvium mantle, is about 150 ohm-m; the apparent resistivity of the Cherokee shale is about 30 ohm-m or less. This striking contrast permits discovery and delineation of the shale areas. Excellent correlation between geology and geophysics was found in test drilling of about 20 low-resistivity anomalies.

Thus resistivity data may be used to indicate favorable drilling targets and facilitate test programs, but the method cannot be used as a direct guide to ore because the Cherokee shale may also occur in depressions, or erosion channels, in the Boone surface or as outliers east of the Cherokee overlap, as well as in slump areas.

The Application of Electric Logging to a Minerals Exploration Program

G. V. KELLER, U. S. Geological Survey, Washington 25, D. C.

The U. S. Geological Survey in cooperation with the Atomic Energy Commission has been carrying out an extensive exploration program for uranium and vanadium ores in the Colorado Plateau

province for several years. In the course of this program many geophysical methods have been tried with varying degrees of success. This paper describes the application of electric logging techniques developed in oil-field work to the problems of the uranium exploration program.

The research consisted of three phases: the electric logging of core holes in order to determine the properties of the ore-bearing formations in place; the laboratory study of the electrical properties of cores and their relation to other physical properties; and an attempt to predict the location of ore-bearing zones away from barren drill holes by means of directional resistivity measurements.

The results indicate that electric logging can be used to determine physical properties of the ore-bearing formation and that directional resistivity measurements about a barren drill hole may indicate the location of areas favorable for exploration.

Resistivity Methods Applied to Some Ground Water Studies

H. Cecil Spicer, U. S. Geological Survey, Washington 25, D. C.

Electrical resistivity studies in two different areas and some problems related to ground-water geophysics are described. Measurements taken near Marshfield, Wisconsin, indicated the presence of an aquifer that was later drilled and found to produce more than 200 gallons of water per minute. Measurements taken near Columbus, Ohio, successfully traced the course of the preglacial buried channel of the Teays River.

A Nuclear Magnetometer

Martin Packard, Varian Associates, Palo Alto, California

A polarized proton sample is allowed to precess in the earth's magnetic field. The frequency of precession is a measure of the field. Airborne and observatory possibilities exist.

The Use of Geophysical Methods for Base Metals Exploration in Northern New Brunswick

Harold O. Seigel, Consulting Geophysicist, Toronto, Ontario

Because of the favorable terrain conditions, the large size, the shallow depth of burial, and the high physical property contrast of many of the ore bodies in the region, various techniques of mining geophysics have proven very successful in the search for lead-zinc-silver-copper mineralization in the Bathurst area of northern New Brunswick.

Since the fall of 1952, two large bodies, each containing more than 30 million tons of ore, and at least one smaller mineable body have been disclosed by an electromagnetic induction technique.

A resistivity technique and, to a lesser extent the self-potential method, have also demonstrated their suitability for primary reconnaissance in the search for the mineralization of interest. Airborne and ground magnetic surveys have been of use in an indirect manner because of the structural information they provide, but have been of little immediate value in the search for the mineralization.

The chief problem encountered has been that of distinguishing between graphitic and sulphide conductors, the former outnumbering the latter by perhaps 50:1. The gravimetric and geochemical (soil sampling) techniques have reduced this problem to one of relatively minor importance.

The exploration sequence that has evolved entails the primary use of an electrical method for detection of the conductors, followed by auxiliary gravimetric and geochemical surveys in the vicinity of the conductors only, to reveal which of these may be caused by sulphide bodies of possible interest, and hence warrant drilling.

Geophysical Case History of the Anacon-Leadridge Base Metal Orebody in New Brunswick, Canada

Stanley H. Ward, McPhar Geophysics Ltd., Toronto, Ontario

Geophysical methods were instrumental during late 1952 and early 1953 in the discovery of three large lead-zinc-copper orebodies in the Bathurst area of New Brunswick. The geological conditions in this locality are particularly favorable for the application of certain geophysical methods.

The manner in which the McPhar electromagnetic method assisted in locating these three orebodies is referred to briefly.

Treated in detail, are the electromagnetic results obtained on the Anacon-Leadridge property of the Brunswick Mining and Smelting Corporation. Although the electromagnetic method led to the ore directly, subsequent experience has shown that it is preferable to apply a secondary exploration tool, such as geochemical soil testing, in order to screen the many electromagnetic anomalies obtained.

Graphitic zones in carbonaceous sediments are a noted cause of electrical anomalies in this area and normally need to be distinguished from massive sulphide zones by auxiliary exploration tools before diamond drilling is attempted.

Results are also presented, for comparison, of magnetic, resistivity, and self-potential tests carried out over the ore zone.

A Case History of the Geophysical Discovery of the Pima Mine, Pima County, Arizona

WALTER E. HEINRICHS, JR., AND ROBERT E. THURMOND, United Geophysical Company, Inc., Tucson, Arizona

During the fall of 1949, a mineral exploration program of a part of Arizona and New Mexico was started by United Geophysical Company. Particular emphasis was placed on the development and use of geophysical applications.

By statistical means, one district was selected which seemed to offer good possibilities for a successful project. The Pima mining district, located about twenty miles south of Tucson, has produced about $20,000,000 in copper, lead, zinc, silver, gold and molybdenum. This production came mostly from small operations. The history of the district is typical of many western mining districts.

The geology of the district in general may be described as a granitic batholith of probable Laramide Age flanked by Paleozoic sedimentary blocks of complicated structure. In most cases the ore deposits of the district have been found in the sediments (mainly limestone) not far from intrusive contacts.

The ore relations and geology of the Mineral Hill area bear directly on the discovery of the Pima Mine, since the Pima Mine is in an alluvial covered area adjacent to Mineral Hill. Investigation of the Mineral Hill geology indicated this alluvial covered area as an exploration possibility.

Studies of the ore occurrence of the district and physical property tests of the ore suggested the selection of geophysical methods to be used. More or less standard techniques were applied, first in reconnaissance fashion and later in detail. Survey of several independent methods indicated anomalous trends in the same area. Interpretation techniques were straightforward and according to standard practice. From the results obtained, drilling was recommended.

Strong mineralization was encountered in the first drill hole. Subsequent drilling indicated a probable economic ore deposit. A 600 foot shaft was sunk through 200 feet of alluvial cover and then into bedrock. Lateral development has now been carried on four levels at 100 foot intervals. Approximately 5,000 feet of development work has been completed to date and the ore deposit is definitely of commercial grade.

The ore occurs in altered limestone in a broad zone of intense alteration (kaolinization and garnetization). Within this alteration zone, it occurs as irregular masses of chalcopyrite of varying size, separated by areas of dissemination. Locally magnetite is associated with the chalcopyrite. The ore may be controlled by a shear zone cutting the bedding at a small angle; however, ore control is not entirely clear. The ore zone, which dips approximately 50 degrees, will average 50 feet in width and 600 to 800 feet in length.

Geophysical Investigations in the Mojave Desert Area of California

DON R. MABEY, U. S. Geological Survey, Salt Lake City, Utah

Gravity, airborne and ground magnetometer, and reflection and refraction seismic investigations have been conducted by the U. S. Geological Survey in the Mojave Desert area of California in a

study of complexly-faulted Tertiary structures and of sediment-filled playa lakes. Both gravity and seismic methods were successfully applied in determining the configuration of bedrock at Searles Lake, where a maximum thickness of sediments of more than 3,000 feet was disclosed. Elsewhere, complexities in the velocity relationships of the near-surface sediments made study of Tertiary structures by the seismic refraction method difficult, but the relatively large magnitude of these shallow features and a favorable density contrast between Tertiary and basement rocks resulted in large gravity anomalies (of the order of 150 gravity units) which clearly delineate structural trends. Magnetic methods proved useful in studying the distribution of volcanic rocks and regional structural trends.

Geophysical Prospecting in the Union of South Africa

J. F. ENSLIN, Geological Survey, Union of South Africa, Pretoria

The major application of geophysical prospecting is in the selection of borehole sites for water by determining:

1. Contacts of igneous intrusions by magnetic and resistivity surveys;
2. Basins of decomposition by resistivity methods;
3. Narrow water-bearing fissures by electromagnetic method;
4. The water-bearing and water-yielding properties of rocks by correlation with their resistivities.

The interpretation of resistivity depth probe curves is by the empirical method, corrected for lateral effects.

In mining, wild-cat drilling for gold reefs in the Witwatersrand System concealed by a deep cover of later rocks has been minimized by gravitational and magnetic surveys.

Resistivity, electromagnetic, gravitational and seismic methods have been applied to problems in the field of engineering geology, including the delineation of areas in dolomite where sink holes are likely to occur.

A New Electromagnetic Field Technique

J. F. ENSLIN, Geological Survey, Union of South Africa, Pretoria

A technique has been developed to locate accurately narrow vertical or inclined structures like joints, fault-zones, mineralized fissures or weathered dikes.

An alternating current of audiofrequency is introduced conductively into the ground at a center-point. Relative or absolute measurements of the tangential component of the resultant horizontal electro-magnetic field is made at stations on circles round the center-point. Maxima, occurring vertically above current concentrations in narrow conducting zones are plotted on a plan of the area and corresponding maxima are easily joined up to delineate the sub-outcrops of such structures.

Phase measurements have been proved to be of minor importance for the above problems.

Instrumentation and Apparatus for a New Electromagnetic Field Technique as Applied in South Africa

G. ff. BELLAIRS, F. G. Slack & Co., Ltd., Johannesburg, Union of South Africa

Geophysical Prospecting for Iron Ore in the Lake Superior Region

L. LLOYAL O. BACON, Michigan College of Mining & Technology, Houghton

A discussion of methods used in prospecting for iron ore in the Lake Superior Region with particular emphasis on the problems encountered as well as limitations of the methods and general interpretational procedures. Examples of typical surveys from the Marquette and Menominee Ranges are presented.

Gravity Meter Surveys at Steep Rock Iron Mines

G. R. JOHNSON, Manager, Radar Exploration Ltd., Toronto, Ontario

A gravity survey involving the use of land, ice and underwater techniques within a small area is unusual. The paper describes the operating method and some of the terrain calculations used on such a survey for Steep Rock Iron Mines Limited.

Gravity was used to guide exploration with the drill and map possible extensions of hematite ore bodies lying at the bottom of a deep lake.

Investigation of Mineral Deposits in Australia by Geophysical Methods

R. F. THYER, Chief Geophysicist, Commonwealth of Australia, Melbourne

Very briefly are discussed the history of geophysical methods in Australia as applied to mineral deposits, the individual methods, how these methods have been used and special cases in which they have given useful results.

By reference to Australian data types of anomalies are illustrated which subsequent drilling proved to be due to a variety of causes. For example, in the use of the electromagnetic method similar types of anomalies have been found to be caused by economic deposits of lead-zinc ore, sparse disseminations of copper sulphides over wide zones but of uneconomic grade, and shear zones filled with salt water.

Conditions of weathering in many of the Australian mineral fields impose special problems for geophysical work. Ways in which, as a result of Australian experience, methods and techniques might be improved are mentioned.

Gravity methods have been used extensively in investigating coalfields, and this work will be described.

Electromagnetic Surface Waves Over Geological Conductors

JAMES R. WAIT, Radio Physics Laboratory, Defense Research Board, Ottawa, Ontario

Expressions for the radiation fields of a vertical electric antenna situated on a horizontally stratified ground are derived. The resulting integrals are evaluated by the modified saddle point method. It is indicated that the well known numerical results for the homogeneous ground can be readily applied to ground wave propagation over a stratified conductor of any number of parallel layers. Curves are prepared which illustrate the essential characteristics of the results.

The most striking feature of this result is that the ground wave is considerably enhanced when the lower inducting strata are at depths of the order of an "electrical skin depth." Apparently under these conditions, energy is reflected from these lower layers in such a phase that it reinforces the direct ground wave. The radiation pattern of the antenna, at low elevation angles, is also shown to have a strong dependence on the nature of the stratification of the ground.

It is concluded that under usual conditions at radio frequencies the near or far zone fields are not affected by the electrical properties of the sub-strata at depths greater than 100 feet. This limitation has been confirmed by experimental tests employing model techniques.

Iron and Titanium Oxide Minerals of Adirondack Rocks and Their Magnetic Properties

J. R. BALSLEY, Geophysicist, USGS, Washington, D. C. AND A. F. BUDDINGTON, Geologist, USGS, Princeton, New Jersey

Rocks from the northwestern Adirondack Mountains, New York, that contain members of the hematite-ilmenite series intermediate between 6 and 96 percent hematite and intermediate members of the Fe_2O_3, FeO-TiO_2 series with up to at least 15 per cent TiO_2 (rutile) uniformly have reverse remanent magnetism. Intermediate members of the hematite-ilmenite series occur alone as accessory minerals over large areas and uniformly give rise to intense negative magnetic anomalies. Where

magnetite and members of the hematite-ilmenite series occur together in different ratios, the magnetic properties are such as to indicate normal remanent magnetism for the grains of magnetite and reverse remanent magnetism for the associated grains of the hematite-ilmenite series.

When specimens of Adirondack rocks containing members of the hematite-ilmenite series are demagnetized by heating above the Curie point and are then cooled in a magnetic field they possess remanent magnetism opposite in direction to that of the magnetic field.

It is tentatively concluded that the reverse remanent magnetization of these rocks and the attendant negative anomalies are caused by the inherent properties of the intermediate members of the hematite-ilmenite series which they contain.

Experiments to determine the mechanism by which these minerals develop reverse remanent magnetization are continuing.

The Ore Contact Method of Electrical Exploration

J. Ewart Blanchard, Geophysicist, Nova Scotia Research Foundation, Halifax

A new method has been developed for determining the size and shape of ore bodies which have a lower resistivity than the surrounding country rock and which have been intersected by a diamond drill hole or underground working. A large number of boundary value problems approximating different shaped ore bodies have been worked out for the electrode configurations used. The quality of the interpretation is limited by the number of measurements which field conditions permit. However. even where only a few measurements can be made the order of magnitude of size can be determined,

The Ionium Method of Age Determination—Recent Developments

Herbert L. Volchok and J. Laurence Kulp, Lamont Geological Observatory, Palisades, New York

The ionium method of age determination is based on the lack of equilibrium in the series uranium, ionium and radium of freshly deposited sediments of the deep sea. The relative concentrations of these elements approach equilibrium ratios with time after deposition; thus a curve of radium concentration as a function of depth in the core should exhibit a shape in accordance with known radioactive equilibrium theory. The most reliable dates appear to be obtained from cores homogeneous in sediment type and uniform in their depositional rate.

Surface area measurements have been made on the material of two cores dated by the ionium method. The results point to adsorption as the mechanism of ionium enrichment. In the case of the "ideal" core, the surface area was found to be relatively constant throughout its length. The second core which exhibits anomalous concentrations of radium at several depths was found to have a direct relationship between radium and surface area in the upper, youngest section.

Since the theory of the ionium method is concerned only with ionium derived from the ocean water, any ionium contained within the rock particles prior to its oceanic deposition is in excess, and will cause further anomalies in the radium-depth curve. Therefore, studies of the ratio of adsorbed total radium of the core material are now in progress. It is hoped that quantitative measurements of this ratio will permit ionium dating of cores not previously useable.

Subsurface Formation Density Logging

G. R. Newton, J. E. Skinner, and D. Silverman, Stanolind Oil and Gas Company, Tulsa, Oklahoma

An instrument for logging the densities of subsurface formations in drilling wells, which utilizes the absorption of gamma rays in the rock as a function of density, has been developed. Calibration of the instrument is carried out in a series of model wells formed in materials of various known densities. Response of the instrument is affected by hole size, so that a caliper log of a well is used interpretively to compensate for varying hole diameters. Methods for automatic diameter compensation have been devised.

Close contact between the instrument and the borehole face is required for accurate measurement. This condition is readily obtained in smooth bore holes where comparisons of logged densities with densities measured on cores showed differences averaging of the order of 0.05 grams per cc. In rough-walled sections the average difference was somewhat higher.

Calculations of formation porosities are made from the density log, based on an inverse relationship between density and porosity. The correlation obtained between log-derived porosities and measured core porosities indicates that the accuracy is sufficiently good to make this information useful for well completion decisions and oil reserve calculations.

Public Relations in Canadian Mining Geophysics

CANADIAN EXPLORATION GEOPHYSICISTS (Presented by HAROLD O. SEIGEL, Toronto, Ont.)

Whereas the science of geophysics has been established as a successful means of mineral exploration in Canada, there is still the need for considerable education of the mining community in general as to the capabilities and limitations of the various techniques employed. The Canadian Exploration Geophysicists are endeavoring in every possible way to further the use of sound techniques by highly qualified personnel as a counter-measure against the aura of skepticism and distrust of the science of geophysics that has resulted from certain ill-advised applications of geophysical methods and techniques.

The Canadian Exploration Geophysicists are attempting to attack this problem at its root by disseminating basic information concerning the methods of mining geophysics through publication of articles and through public lectures and demonstrations directed to all those who are concerned with mining—geologists, geophysicists, prospectors and the investing public. The encouragment of students to undertake geophysics as a career in order to ensure the flow of the proper type of trained personnel, and also the enhancement of the professional status of mining geophysicists through group action are all means to this end.

Geophysical and Geological Investigations in the Gulf of Mexico

MAURICE EWING, J. L. WORZEL, D. B. ERICSON, AND BRUCE C. HEEZEN, Lamont Geological Observatory, Palisades, New York

In 1953 the Research Vessels *Vema* and *Atlantis* spent about three weeks in the Gulf of Mexico. Coring, seismic refraction and topographic studies were undertaken. The results point to the southern half of the Gulf of Mexico as a typical ocean basin with a profound change at the foot of the continental slope. Many sediment cores longer than 30 feet were taken in the Sigsbee Deep. The abrupt change separates approximately 3 feet of Recent sediments from Wisconsin, in which all cores ended.

Cotton Valley Strand-Line Fields in North Louisiana

JOHN H. CRUMP, Southwest Gas Production Company, Monroe, Louisiana

The recent history of the search for and the development of Cotton Valley gas-distillate fields is presented, and the probable direction of future exploration of these sands is discussed.

Helicopters—A Versatile Exploration Tool

FRANK W. LEE, Bell-Helicopter, Lafayette, Louisiana

During the past five years many of the major oil companies have utilized the helicopter to transport their exploration equipment and personnel through the inaccessible areas of the Western Hemisphere.

An all helicopter seismograph operation can be conducted in an efficient and safe manner with the helicopters moving the crew, equipment and supplies from a quarterboat or a land base to the prospect in the field. Once in the field the helicopters accomplish the surveying, move the "line," the drillers as well as supply the crew with powder and casing, etc.

Using helicopters to transport the gravity meter, operator and, when necessary, surveyors and

towers has proved to be the most economical method of completing a gravity survey. When possible, aerial photographs are used to locate the stations picked for gravimetric readings, as naturally this method is by far the fastest of any used. When necessary the helicopters transport portable aluminum towers for transit men to triangulate the location of the helicopter as it hovers over the desired gravity station.

The helicopter has become indispensable in pipeline surveys, well refraction operations, we location surveys . . . as well as numerous other activities in the oil industry. In many cases it is possible to obtain permits to conduct either seismograph or gravity surveys in areas heretofore unobtainable because of damages to the land that occur when using other types of transportation facilities.

Transmission Characteristics of Near Surface Layers, Barton County, Kansas

ROBERT B. FISHER, Geophysical Research Corporation, Tulsa, Oklahoma

This paper describes a method of making measurements of earth materials in place by examining pulses recorded at several depths in the earth adjoining a shot hole.

The recorded pulses were analyzed by means of a Henrici rolling sphere analyzer to obtain their Fourier spectra. Point by point division of two spectra yielded the transfer characteristic of the earth materials between two geophone positions.

A point of special interest is the extremely rapid attenuation of the high frequency components of the waves in the very shallow layers of the earth.

A Field Evaluation of the Electromagnetic Reflection Method

ROBERT VAN NOSTRAND, Magnolia Petroleum Company, AND ALBERT ORSINGER, Earl Lipscomb Associates, Dallas, Texas

In previous publications, Yost et al. (GEOPHYSICS, XVII, pp. 89–103 and 806–826) have outlined the general theory of electromagnetic wave propagation along an interface such as the air-earth boundary and have described model experiments in which this theory was verified. Equipment, similar to that described for the laboratory experiments, has been assembled for field use. Two large loops, one for transmitting and the second for receiving, are laid on the surface of the ground and a pulsed current is passed through the transmitting loop. A similar arrangement of loops is placed on the surface of a metallic model and the signals received by the two receiving loops are mixed in opposition. The layering in the model is then manipulated until the difference signal is a minimum, which condition signifies that the actual earth has been approximated in the model considering the appropriate scaling factors. Using this technique at five stations in Dallas County, Texas, where the depth of the Austin chalk-Eagle Ford shale contact varies from 50 to 400 feet, this depth was determined within an average accuracy of about five per cent.

The Impulsive Response of Planted Geophones

R. G. PIETY, Phillips Petroleum Company, Bartlesville, Oklahoma

In this paper the interaction between the ground and the geophone is described in terms of the response to an impulsive force acting on the geophone. Experimental observations are shown exhibiting the wide range of variation to be expected in field practice. In general a tightly planted geophone is much more highly damped than a geophone resting on the surface. The impulsive response is obtained by dropping a small steel ball on the planted geophone. It is observed that in some cases the behavior indicates that reciprocity between the reception and transmission of a pair of differently planted geophones holds true.

Radioactivity Measurements in the Los Angeles Basin (BY TITLE)

H. WAYNE HOYLMAN, Consultant, Los Angeles, California

This paper discusses some of the results obtained during the past two years of gamma radiation

surveys which have been studied as geophysical data reflecting certain geological conditions. The problem of determining gamma ray anomalies with a continuous recording scintillation counter is discussed. Cross sections and contour maps will be shown of gamma radiation measurements, on the ground and in the air, across certain oil fields and geological structures in the Los Angeles Basin. Some correlations of radioactivity and aeromagnetics with geology will be shown.

VICE-CHAIRMAN'S REPORT ON 24TH ANNUAL MEETING

KIEL AUDITORIUM, ST. LOUIS, MISSOURI

APRIL, 1954

The 24th Annual Meeting of the Society was held in St. Louis in April, in conjunction with the annual meetings of the American Society of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists. Thirty-five technical papers were presented on the SEG program including 17 papers on mining geophysics. Interest in mining geophysics was at a new high with a full day of papers, a high percentage of the papers having been presented by Canadian authors. Abstracts of all technical papers appear elsewhere in this issue.

A total of 699 SEG members were registered, including 80 student members. Total convention registration was 3161, including 428 women and 350 non-member students. Paid registration totalled about 2,300, with 273 registrants indicating membership in both AAPG and SEG. The influence of geographical location of the convention city is apparent as SEG registration at the St. Louis meeting was not appreciably more than SEG registration at recent midwestern regional meetings.

A geographical breakdown of SEG registration follows:

Arizona 3; California—Los Angeles 13; other California 26; Colorado—Denver 27; other Colorado 10; Delaware 2; Illinois 13; Indiana 2; Iowa 2; Kansas 8.

Louisiana—New Orleans 14; Shreveport 16; other Louisiana 8; Maryland 1; Massachusetts 3; Michigan 2; Minnesota 1; Mississippi 3; Missouri 36; Montana 10; Nebraska 1; New Jersey 2; New Mexico 5; New York 15; North Dakota 6.

Ohio 7; Oklahoma—Tulsa 95; other Oklahoma 35; Pennsylvania 22; Tennessee 2; Texas—Dallas 71; Fort Worth 20; Houston 104; other Texas 41.

Utah 2; Virginia 1; Wisconsin 7; Wyoming 7; Washington, D. C. 7; Canada—Calgary 22; other Canada 10; Europe 3; Mexico 2; Venezuela 2.

A great many persons contributed generously of their time to make the convention successful. General Chairman Graham Moody did a fine job of organization and direction. General Vice-Chairman Noel Stearn had a particularly heavy load, being on the scene in St. Louis. The AAPG Business Office was responsible for many of the intricate details of arrangement and the smooth running of the whole show would not have been possible without the splendid efforts of Mr. Robert H. Dott and Dr. E. W. Ellsworth.

The student section of the SEG at St. Louis University gave freely and generously of their time during the convention and are due the thanks of the Society. The student section president, John J. McCormick, had the unusual distinction of serving on two of the convention committees.

The convention was a financial success, the aim having been to break even. While the final accounting has not been made, the income was about $39,000, and the outgo about $36,000, leaving a surplus of about $3,000.

KARL DYK
Convention Vice-Chairman for SEG

MEETING ON VEHICULAR COMMUNICATIONS

The professional group on Vehicular Communications of the Institute of Radio Engineers will hold its fifth annual meeting in Houston, Texas on September 30 to October 1, 1954. The theme of the meeting is "The Communications Engineers' Role in American Industry." The host for the meeting is the Houston section of the IRE. Walton Greer is chairman of this section.

PROPOSED AMENDMENTS TO THE BY-LAWS OF THE SOCIETY

The following By-laws amendments have been proposed to the Society's Council by the Constitution and By-laws Committee under the Chairmanship of Dr. W. M. Rust, Jr. These amendments call for new procedures for election to membership and for suspension and reinstatement of members delinquent in dues.

Sections 4, 5, and 6 of Article 3 of the By-laws should be revised respectively, to read as follows:

SECTION 4: The name of each applicant for Active membership shall be published in the next regular issue of the Society's Journal for approval by the membership at large. If no objection is received within thirty days after this publication, the applicant shall be deemed approved by the membership at large.

SECTION 5: An applicant for Active or Associate membership must be approved by a majority of the Executive Committee. An applicant for Student membership must be approved by the Secretary-Treasurer.

SECTION 6: When an applicant has been approved, he shall be notified in writing by the Business Manager. If he fails to make payment of full annual dues within four months after such notification, the Executive Committee may rescind his election. His membership shall date from the first day of the calendar year in which he makes his initial payment of dues and he shall receive the regular Society publications for that year.

Sections 1, 2, 3, and 4 of Article 6 of the By-laws should be revised, respectively, to read:

SECTION 1: Any member who fails to pay his dues by the last day of the calendar year shall be automatically suspended from membership on that day. While he is suspended, he shall have no rights in the Society and shall not be charged any dues.

SECTION 2: A member who has been suspended more than one year shall be dropped from the Society by the Executive Committee.

SECTION 3: A suspended member will automatically be reinstated by payment of outstanding dues and obligations and the dues for the current calendar year.

SECTION 4: A member who has been dropped under the provisions of Section 2 of this Article may be reinstated by a majority vote of the Executive Committee subject to the payment of outstanding dues and obligations and the dues for the current calendar year.

ANNOUNCEMENTS

BILLINGS AND NEW ORLEANS SECTIONS CHARTERED

The MONTANA GEOPHYSICAL SOCIETY, Billings, became a Local Section of the Society of Exploration Geophysicists during the 1954 Annual Meeting. The final signature of approval of the petition for affiliation was affixed April 12, 1954. The first meeting of the group was held October 16, 1953, with a total of fifty-three persons present, including twenty-five active members of SEG. At the second meeting, on November 9, 1953, nominees for office were announced. The first annual meeting was held December 14, 1953, when it was announced that the Montana Geophysical Society had an initial membership of fifty-eight, all of whom had paid their dues. Also at this meeting the results of the first mail ballot were announced, electing the following officers: H. V. Crowder, President; J. R. Willcockson, 1st Vice-President; S. R. Marsh, 2nd Vice-President; and J. D. Sides, Secretary-Treasurer. Elected to serve on the Executive Committee were R. W. Gemmer, 1st Past President and Donald Crary, 2nd Past President.

The SOUTHEASTERN GEOPHYSICAL SOCIETY, New Orleans, Louisiana, became a Local Section when its petition for affiliation was approved April 1, 1954. The organizational meeting of the New Orleans society was held on December 21, 1953, when the petition was signed by thirty-six Active members of SEG. A total of eighty-one persons attended the meeting, and elected the following officers: E. H. Shannon, President; D. D. Utterback, Vice-President; Merrill Smith, Secretary-Treasurer; and B. H. Treybig, District Representative.

PRELIMINARY ANNOUNCEMENT OF ANNUAL MIDWESTERN REGIONAL MEETING

The Annual Midwestern Regional Meeting of the SEG will be held in Dallas, Texas on Thursday and Friday, November 18–19, 1954. The headquarters for the meeting will be the Hotel Adolphus. The principal sponsor this year will be the Dallas Geophysical Society. Other sponsoring societies are the Geophysical Society of Tulsa, The Fort Worth Geophysical Society, the Ark-La-Tex Geophysical Society, The Permian Basin Geophysical Society, and the Oklahoma City Geophysical Society.

The General Chairman for the convention is Robert C. Dunlap, Jr., Geophysical Service Inc., Dallas. Mr. Dunlap has announced the names of the various committee chairmen as follows: Program—Maurice Tripp, Research, Inc.; Finance—Martin Kelsey, Rayflex Exploration Co.; Entertainment—Lester Logue, Exploration Surveys, Inc.; Arrangements—Chester J. Donnally, Donnally Geophysical Co.; Program Publication—John W. Wilson, Geophysical Service Inc.; Publicity—John A. Lester, Magnolia Petroleum Co.; and Housing—John T. Geer, Magnolia Petroleum Co. All of the chairmen are from Dallas.

A form for requesting hotel reservations will be sent out to all members from the Society headquarters during the summer. Papers are solicited for the program and titles of papers proposed for the meeting should be sent to Dr. Tripp or to one of the local program committee representatives as soon as possible.

FELLOWSHIPS AND SCHOLARSHIPS IN GEOPHYSICS

A number of scholarships and fellowships in geophysics and geophysical engineering are to be awarded by oil companies for the 1954–55 academic year.

The Atlantic Refining Company has established one scholarship in geophysics at Colorado School of Mines and one at St. Louis University.

Stanolind Oil and Gas Company fellowships in geophysics are being offered at the University of California (Berkeley) and at Columbia University. The fellowships carry a $1,500 stipend and provide, in addition, full payment of tuition and laboratory fees. Selection of the fellows will be made by the respective schools in cooperation with Stanolind.

The Shell Fellowship Committee of Shell Oil Company and other Shell corporations will spend $263,500 during the next academic year on grants for fundamental research and on fellowships. The research grants, which have been made to fourteen universities, are for $7,500 each. Geophysical engineering is among the fields in which grants have been made. Geophysics is also included among the fields in which graduate fellowships are to be awarded. The fellows are selected by their schools and each fellow receives a stipend of $1,500 plus tuition and fees. The schools receive an additional amount to cover fellows' research expenses.

PERSONAL ITEMS

WILLIAM M. BARRET has announced a change of address for William M. Barret, Inc. with occupation of its new offices, laboratories, and shops at Linwood Avenue and Dalzell Street, Shreveport, Louisiana.

STEPHEN M. SIMPSON, JR., has been promoted to the rank of assistant professor, Department of Geology and Geophysics, Massachusetts Institute of Technology, and GORDON MACDONALD has been appointed to the position of assistant professor in the department.

MORRIS M. SLOTNICK has joined the Standard-Vacuum Oil Co. as geophysical consultant and advisor for the company's activities in the Far East. While he will make his headquarters at Stanvac's New York office, he will make occasional visits overseas to field operations. Dr. Slotnick is a former Editor of GEOPHYSICS.

C. SHELDON SHARP, formerly geophysicist with the Arabian American Oil Co. at Dhahran, Saudi Arabia, has transferred to The Carter Oil Co. and is now acting as interpreter of gravity surveys for the Creole Petroleum Corp. in Venezuela. His mail address is GM-3 Exploration Department, Care of Mr. D. C. Meyer, Creole Petroleum Corp., Apartado 889, Caracas, Venezuela.

HENRY L. RASÉ, JR., of Gulf Research & Development Company and formerly party chief at Ardmore, Oklahoma, has been transferred to Denver, Colorado as Area Geophysicist.

Appointment of R. D. HOLLAND and W. H. GIBSON as assistants to division manager, Geophysical Division of The Texas Company's Producing Department, effective April 1, was announced by J. N. TROXELL, general manager of the Producing Department, and O. B. HOCKER, division manager, Geophysical Division. Mr. Gibson will have headquarters in Houston and Mr. Holland will be located at Calgary, Alberta, Canada, and will be in charge of geophysical operations in western Canada.

J. O. CANFIELD has been promoted from geophysicist to geophysical supervisor in the Colombian division of Texas Petroleum Co.

E. L. MOUNT is now Central Regional Geophysicist for Continental Oil Co., with office in Oklahoma City. He was formerly Assistant to the Central Regional Geophysicist.

R. N. BRUYERE, whose position was listed as Party Chief in the membership list, is Geophysicist for The Texas Company, Houston, Texas.

AUGUST F. BECK has resigned from Imperial Oil, Ltd., to become Vice-President and General Manager of Canadian Export Gas, Ltd., Calgary, Alberta.

RICHARD BREWER, formerly District Seismic Supervisor for The Atlantic Refining Co., Shreveport, has become Vice-President and Supervisor of Continental Geophysical Co., Fort Worth, Texas.

W. T. BUCKINGHAM, of Western Geophysical Co., is now located at Mendenhall, Mississippi.

PERTEV I. BEDIZ has been appointed Vice-President of Century Geophysical Corporation of Canada.

WALTER D. BAIRD has opened offices as Consulting Geophysicist at 911 Neil P. Anderson Bldg., Fort Worth, Texas.

THOMAS J. BEVAN and PAUL W. FULLERTON, JR. announce the opening of Southwestern Computing Service, with offices at 910 South Boston, Tulsa, Oklahoma. The firm offers an engineering and accounting service utilizing punched cards and high speed computing machinery.

FLOYD ACKLIN, JR., with Richardson & Bass, is now located at 701 North Canal, Carlsbad, New Mexico.

WILLIAM D. AGERTON is now located in Sinton, Texas, and receives his mail at P.O. Box 968.

J. E. BARTHELEMY, JR. has changed his mailing address to Box 692, Brookhaven, Mississippi.

WALTER D. BAIRD, consulting geophysicist, has offices at 911 Neil P. Anderson Building, Fort Worth 2, Texas.

GORDON R. BELL, District Geologist for Western Gulf Oil Co., has moved to 2405 Thompson Blvd., Ventura, California.

NORMAN A. CARTER has moved from Pawnee, Oklahoma to 127 South Sixth St., Henrietta, Oklahoma.

K. M. CLARK, JR., Party Chief for The Texas Company, has moved from Enid, Oklahoma to Canadian, Texas, where he may be addressed at P.O. Box 812.

DONALD W. DANZ has advanced from Intermediate Geophysicist to Geophysicist for Stanolind Oil & Gas Co., and has moved from Roswell, New Mexico, to Midland, Texas.

WILLIAM HORACE DIMENT is now with The California Company, at 800 The California Company Building, New Orleans, Louisiana.

ROLLIN E. DAVIS has moved from Big Spring, Texas to 830 8th Avenue West, Calgary, Alberta, Canada.

WILLIAM H. DOUGHTY, formerly at Tatum, New Mexico, has moved to Bakersfield, California, where his mailing address is Box 1528.

GEORGE K. FEGAN, computer with Keystone Exploration Company, is now located at the company's headquarters, 2813 Westheimer Road, Houston 6, Texas.

HENRY H. FUQUA, JR., Cardinal Geophysical Co., Inc., has changed his address to the company offices at 542 Petroleum Building, Wichita, Kansas.

JAMES C. FINLAY has moved from Edmonton, Alberta to 491 Stiles Street, Winnipeg, Manitoba, Canada.

WILL ALEX GROSSE, Party Chief for The Atlantic Refining Co., has moved from Rapid City, South Dakota to Mobridge, South Dakota.

WILLIAM H. GAYMAN, formerly Research Engineer for Northrop Aircraft, Inc., is now in the Structures Division of Aerophysics Development Corporation, 553 E. Walnut Street, Pasadena, California.

B. A. HEIDT is now Party Chief for Liberty Exploration Company, and receives his mail at Box 7147, Tulsa 18, Oklahoma.

WILEY R. HAGGARD, JR., Computer for Continental Oil Company, has returned to the company headquarters in Ponca City, Oklahoma.

HARRY G. HADLER recently resigned from his position as Area Geologist of southern Oklahoma for Stanolind Oil & Gas Co., to become associated as geologist with the Fain-Porter Drilling Company, 417 NW 16th Street, Oklahoma City, Oklahoma.

CORBY L. HART, Supervisor for National Geophysical Co., Inc., Dallas, Texas, has moved to Dickinson, North Dakota, where his mailing address is P.O. Box 606.

JOHN H. HIDY, formerly Chief Development Engineer with Geophysical Development Corp., is now Vice-President of Frost Geophysical Corporation, Box 58, Tulsa 1, Oklahoma.

RALPH C. HOLMER, formerly Chief Geophysicist for Kennecott Copper Corp., is now Chief Geophysicist for Bear Creek Mining Company, 516 Acoma Street, Denver 4, Colorado.

JAMES G. JACKSON, JR., Party Chief with Western Geophysical Company, has moved from La Canada to 507C Granada, Glendale, California.

E. D. LYNTON retired from the Standard Oil Co. of California on April 1, 1953. He recently resigned from the Defense Materials Procurement Agency in London, and is now living at 422 Beloit Avenue, Berkeley 8, California, where he opened a consulting office as a petroleum and mining engineer.

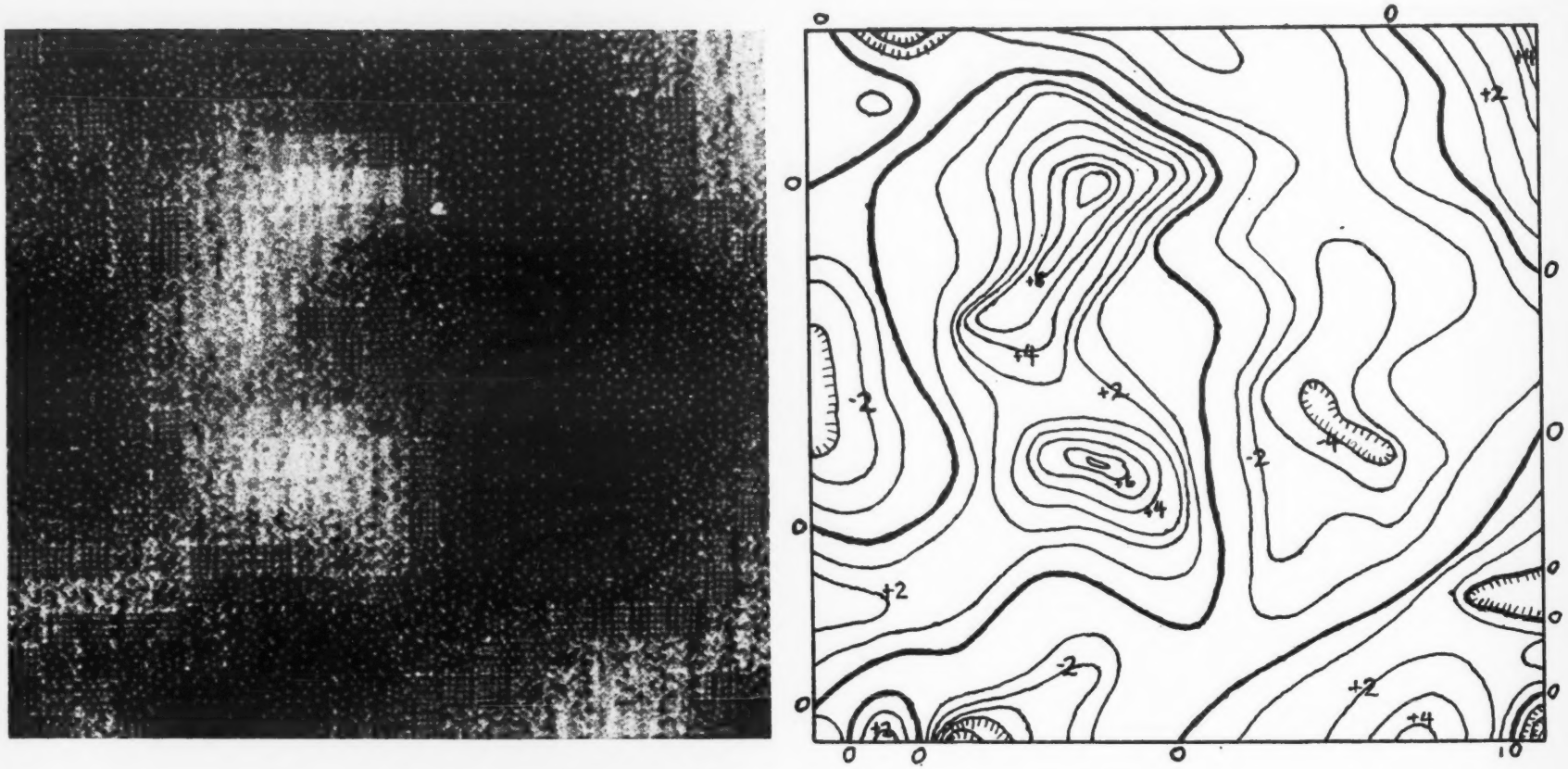

FIG. 9. The density plot display as compared with the more usual contour map.

CORRECTED FIGURE FROM "LEAST SQUARES POLYNOMIAL FITTING TO GRAVITATIONAL DATA AND DENSITY PLOTTING BY DIGITAL COMPUTERS" by Stephen M. Simpson, Jr. (*GEOPHYSICS*, Volume XIX, April, 1954, Page 268)

As originally printed, Figure 9 of this paper showed the left hand and right hand portions in wrong orientation with respect to one another. The figure is shown correctly here, with the contour map and density-plot display in proper relation.—*The Editor*

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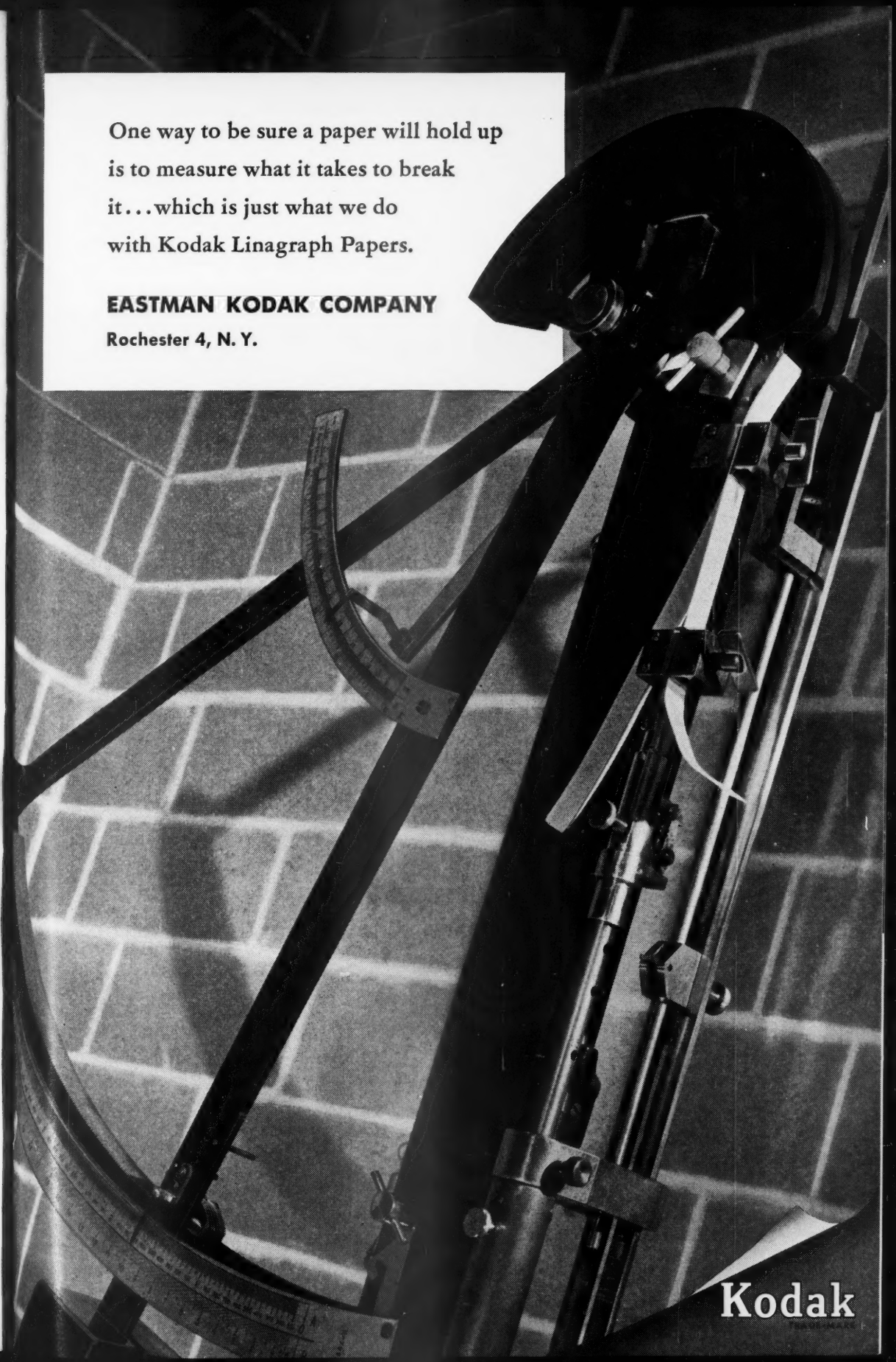
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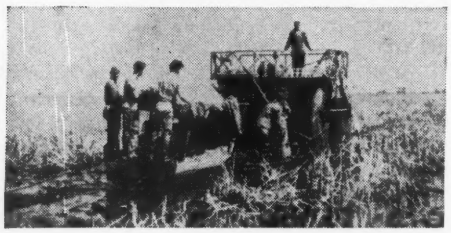

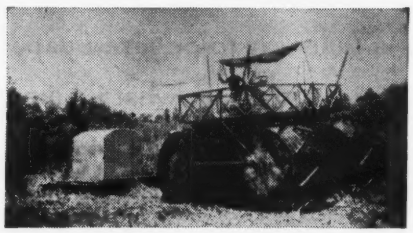

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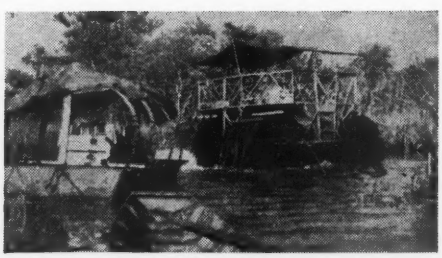

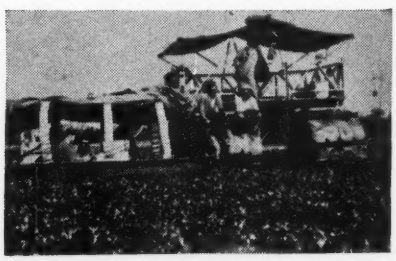

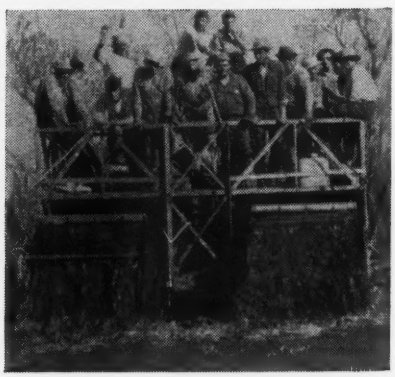

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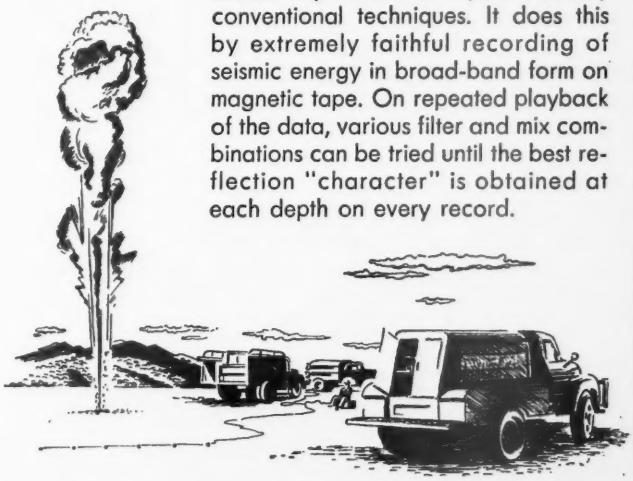

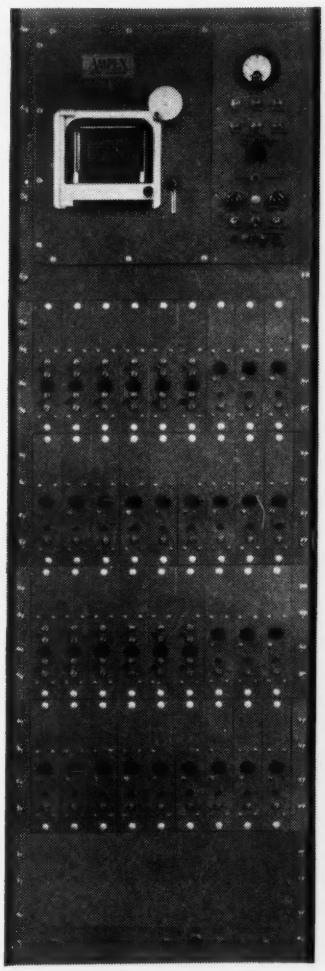

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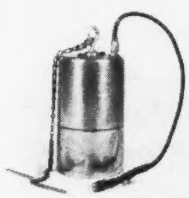

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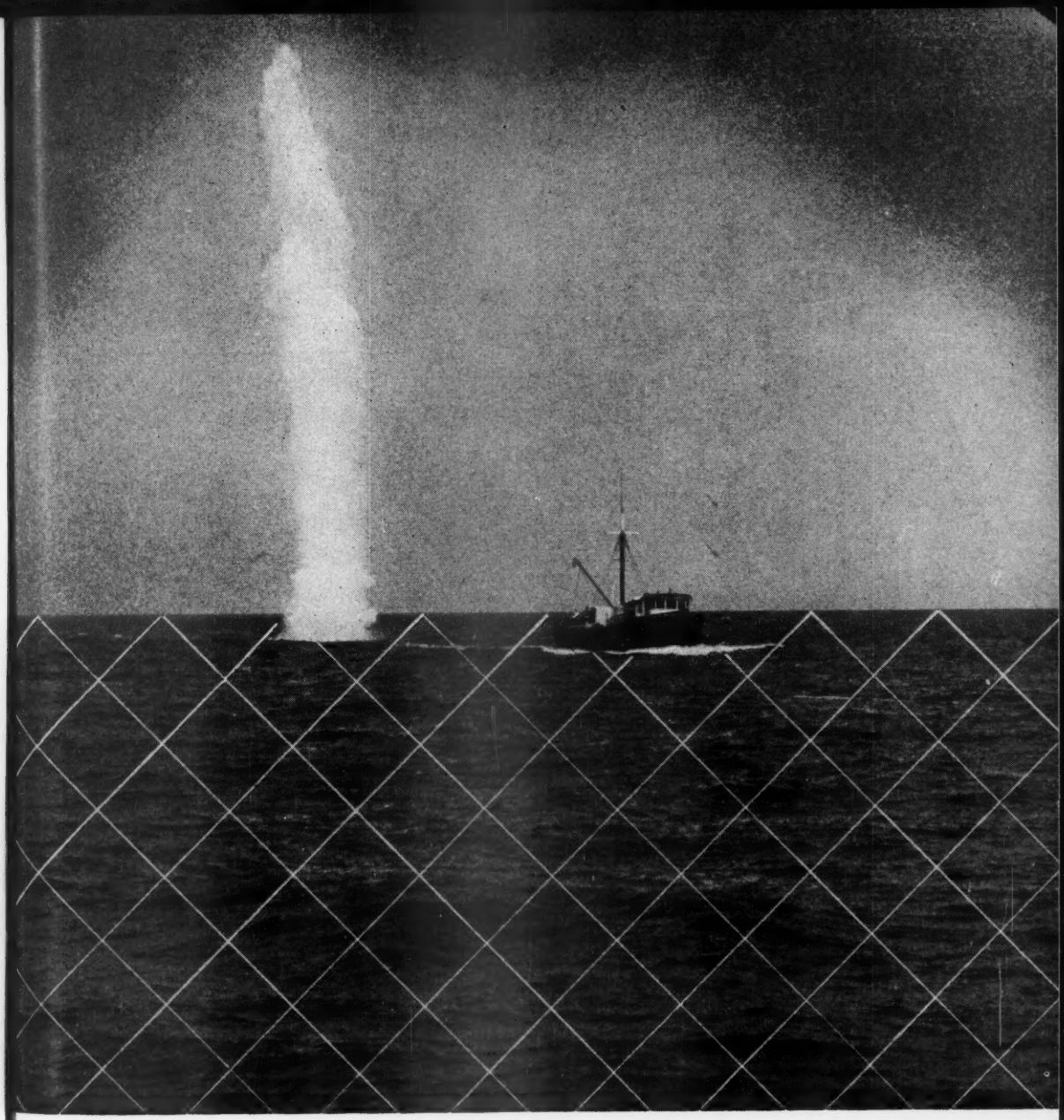

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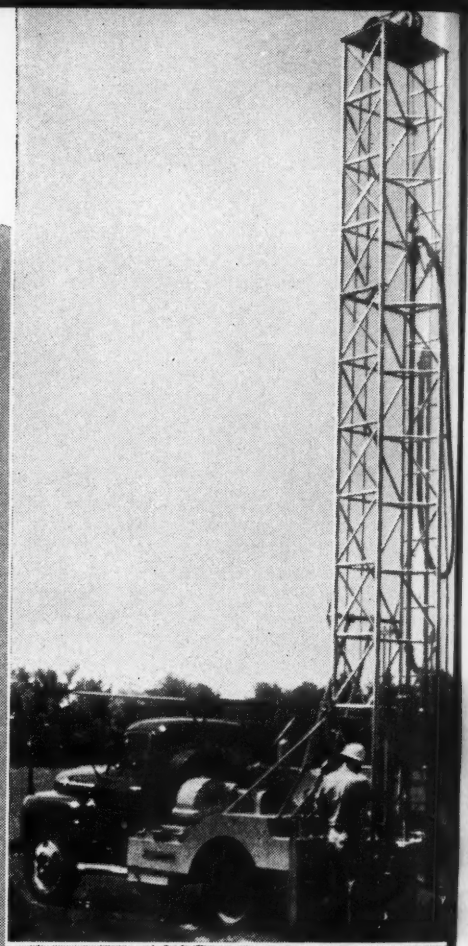

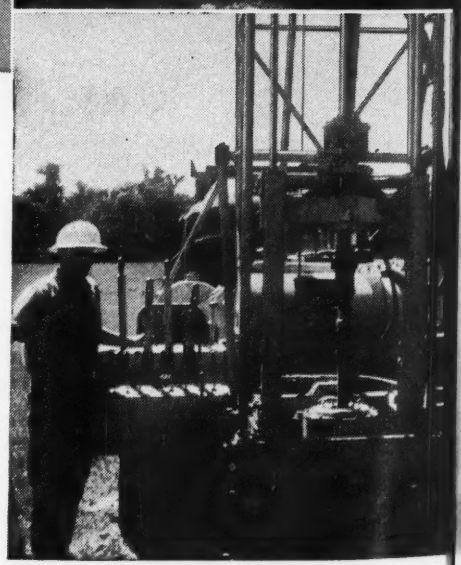

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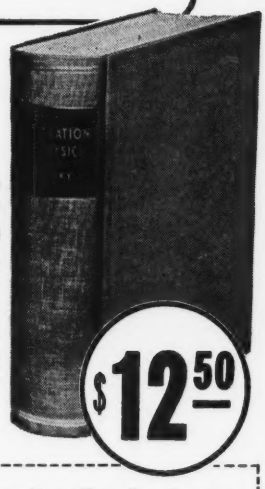

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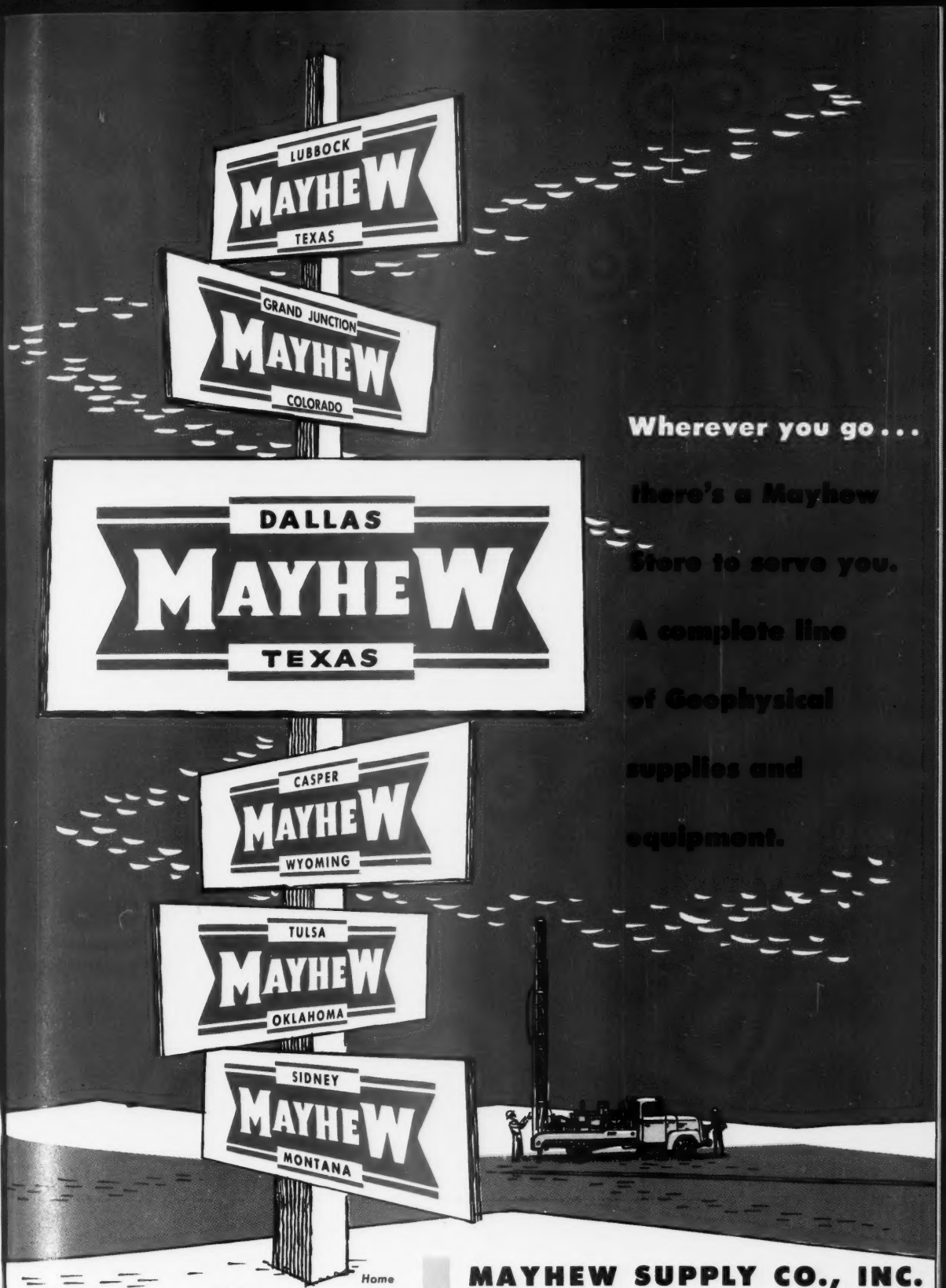

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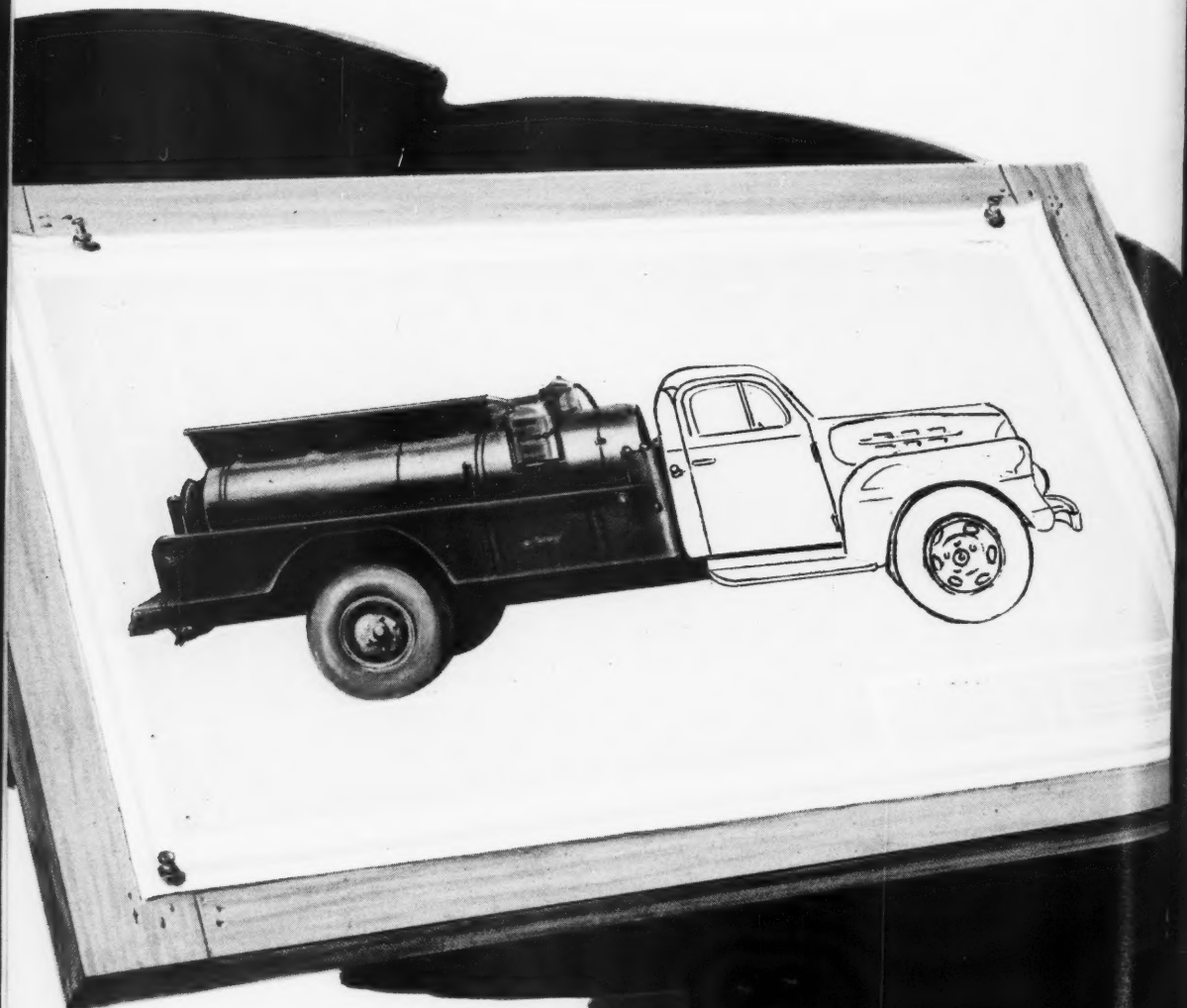

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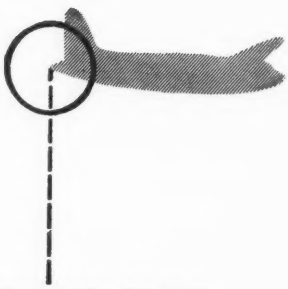

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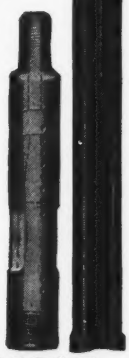

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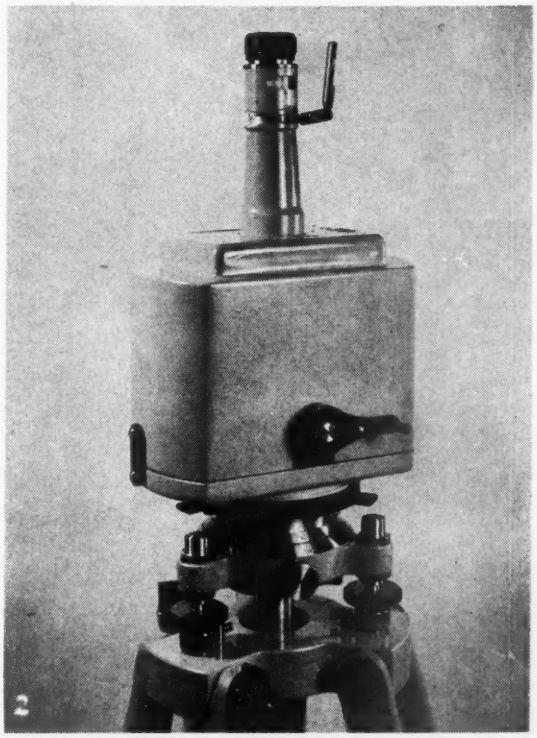

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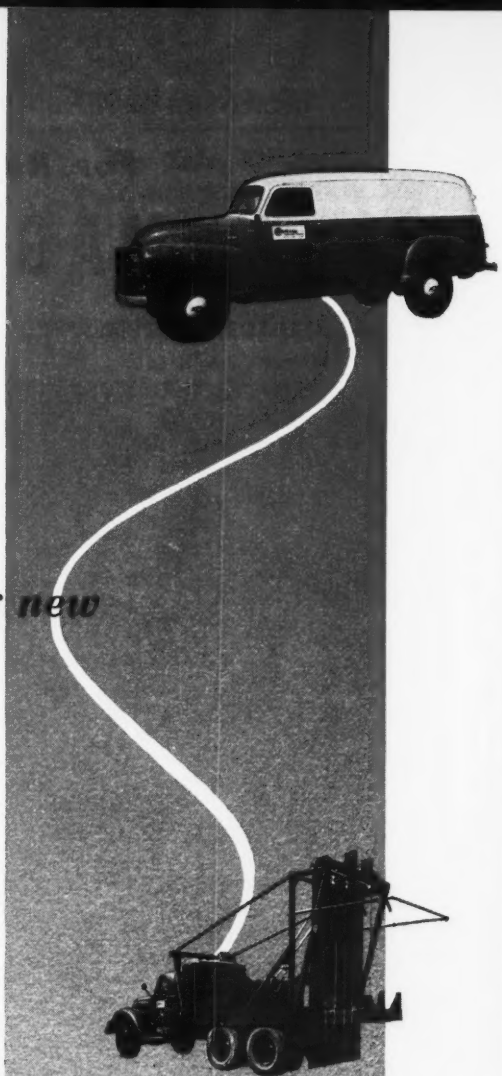

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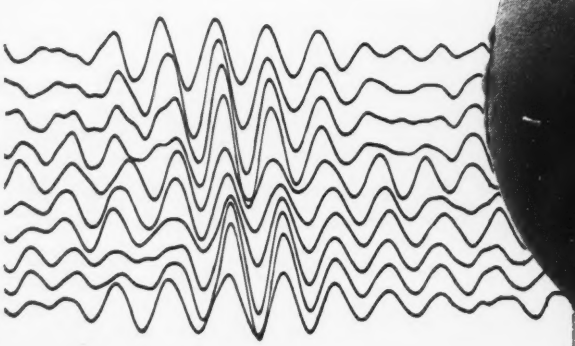

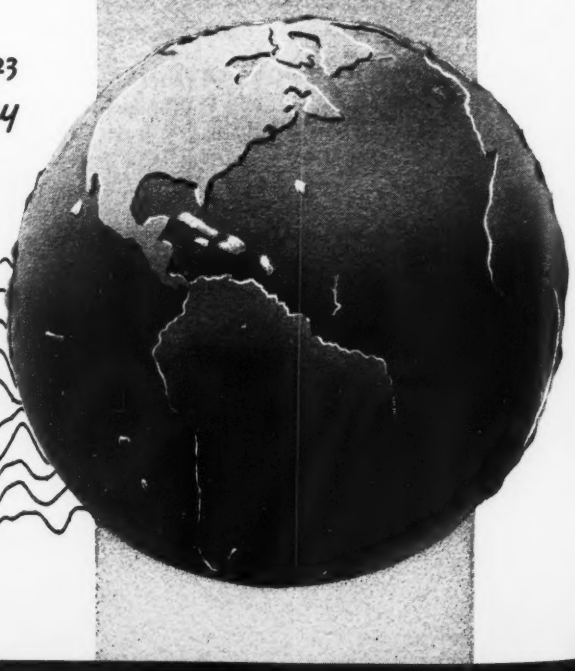

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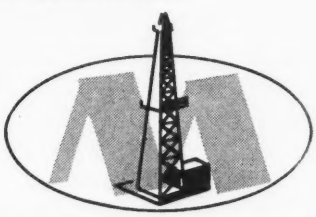

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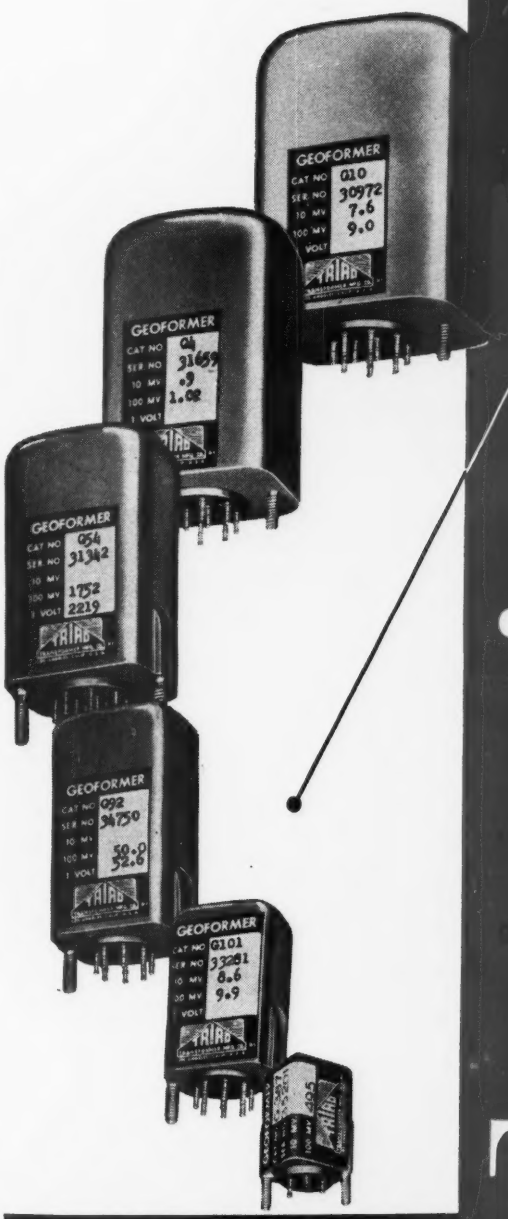

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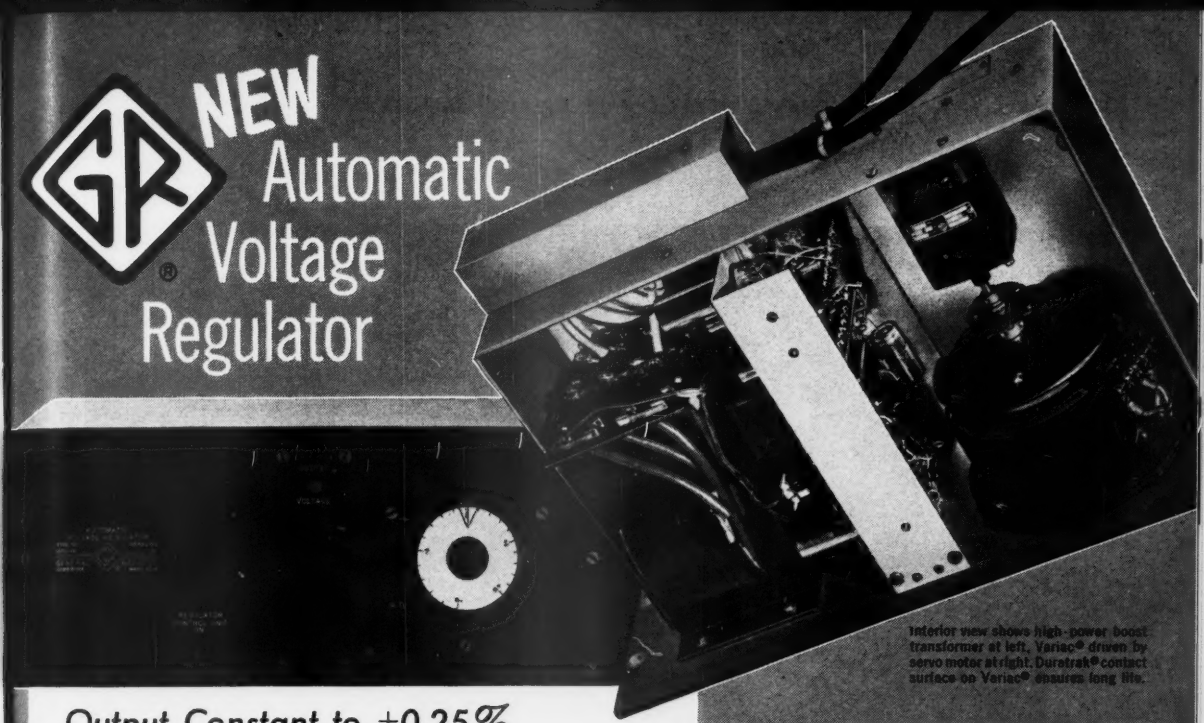

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Features you get with the GR 115-volt, 60-cycle Automatic Voltage Regulator . . .

SPEED *This instrument does things in fractions of a second — response is 10 volts per second*

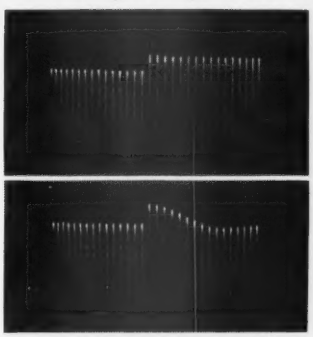
HIGH ACCURACY *Output held constant to within ±0.25% of voltage selected*

±10% SELECTION IN OUTPUT VOLTAGE *Output may be set for any desired value from 104 to 127 volts*

CORRECTS LINE VOLTAGE FLUCTUATIONS OVER WIDE RANGE *±10% of selected output voltage, ±20% or ±40% at reduced accuracy and power rating*

HIGH POWER *Handles 50-amps (6 KVA)*

EXCELLENT TRANSIENT RESPONSE *Adjustments permit setting response characteristic desired — adjustable for no overshoot (see oscillograms)*



Oscillograms illustrate high-speed response of typical G-R Automatic Voltage Regulator. Illustrated at top, is sudden 1% change in 60-cycle voltage input to Regulator. Bottom oscillogram shows instrument correcting for this change in 8 cycles (0.13 seconds)

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VOLTAGE CORRECTION INDICATED *Panel dial provides continuous indication*

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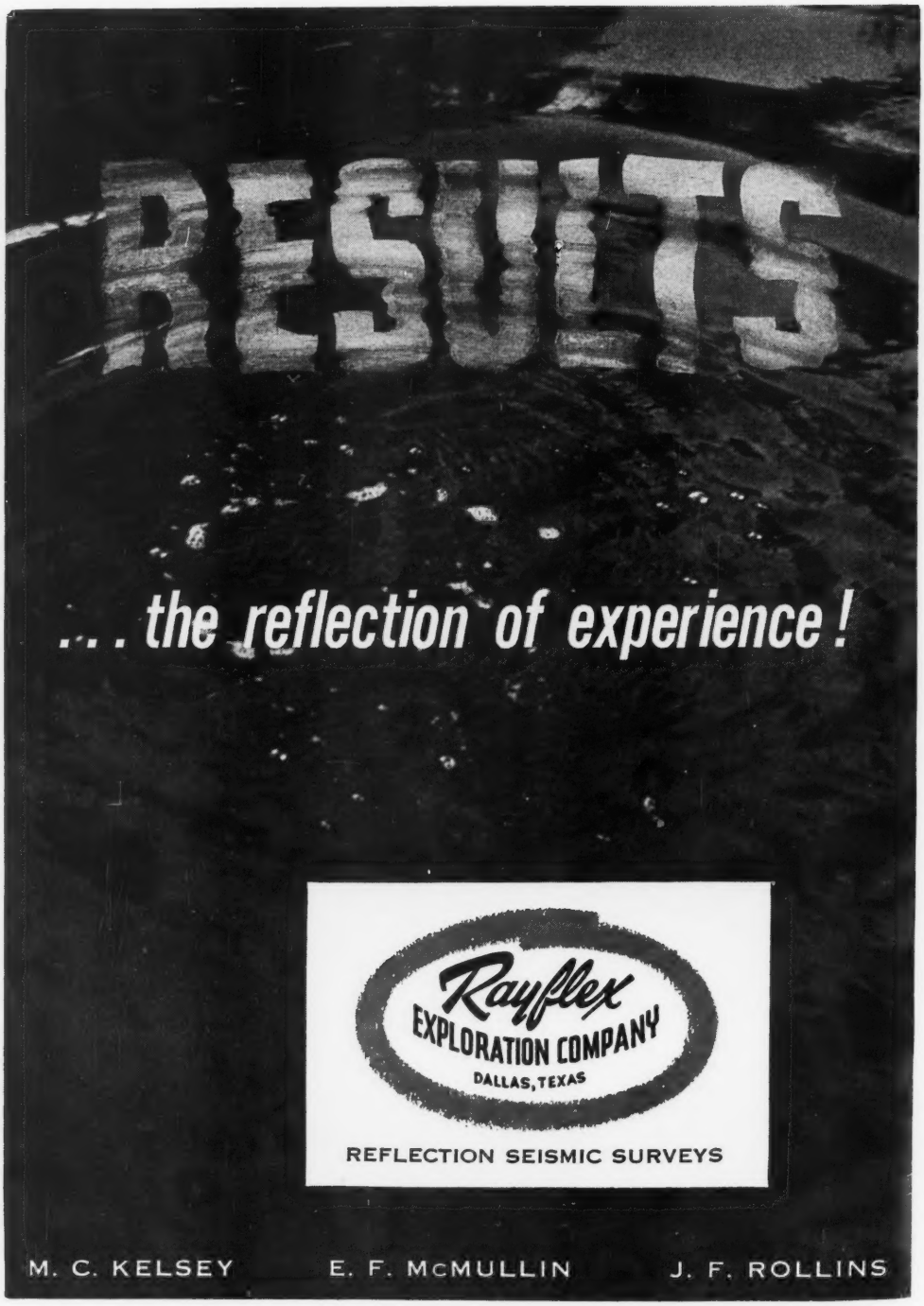
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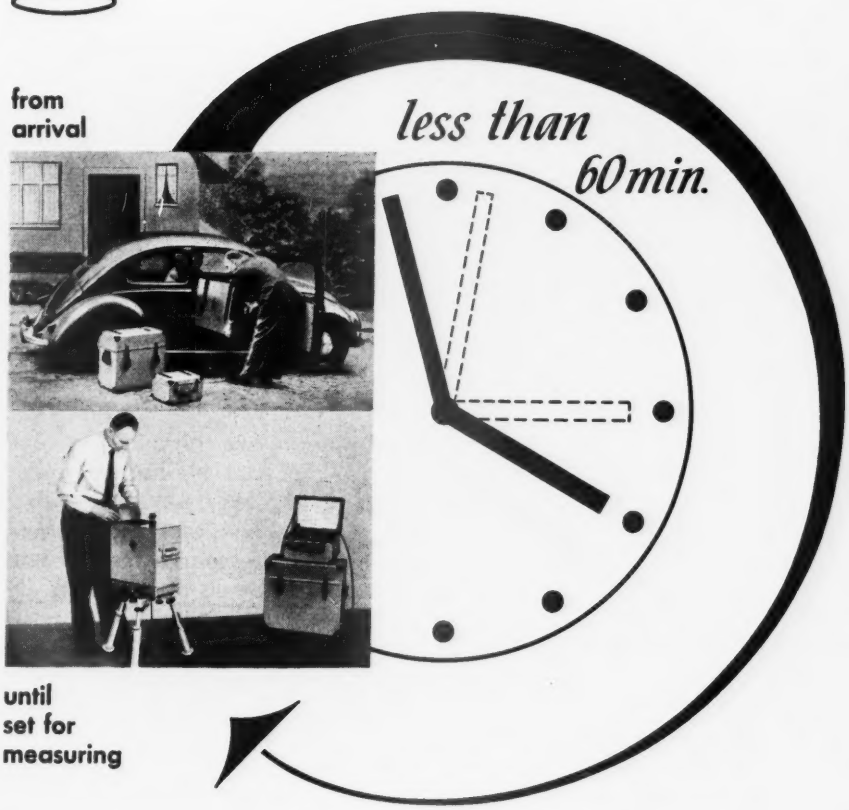

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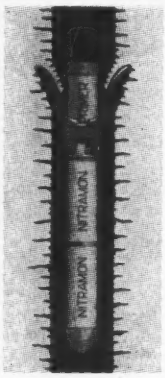

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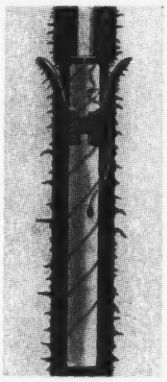

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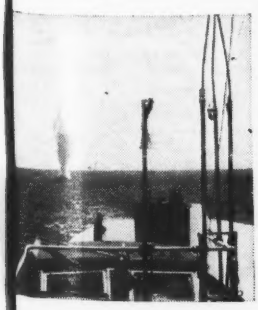

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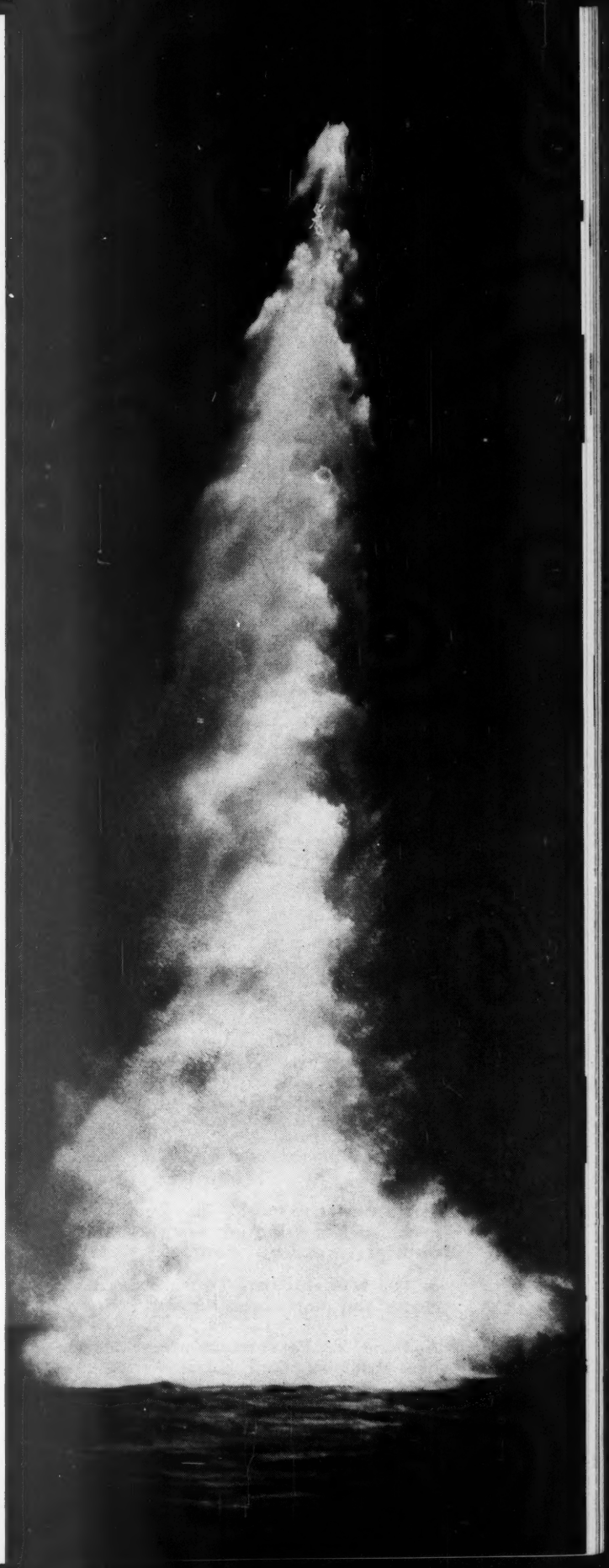

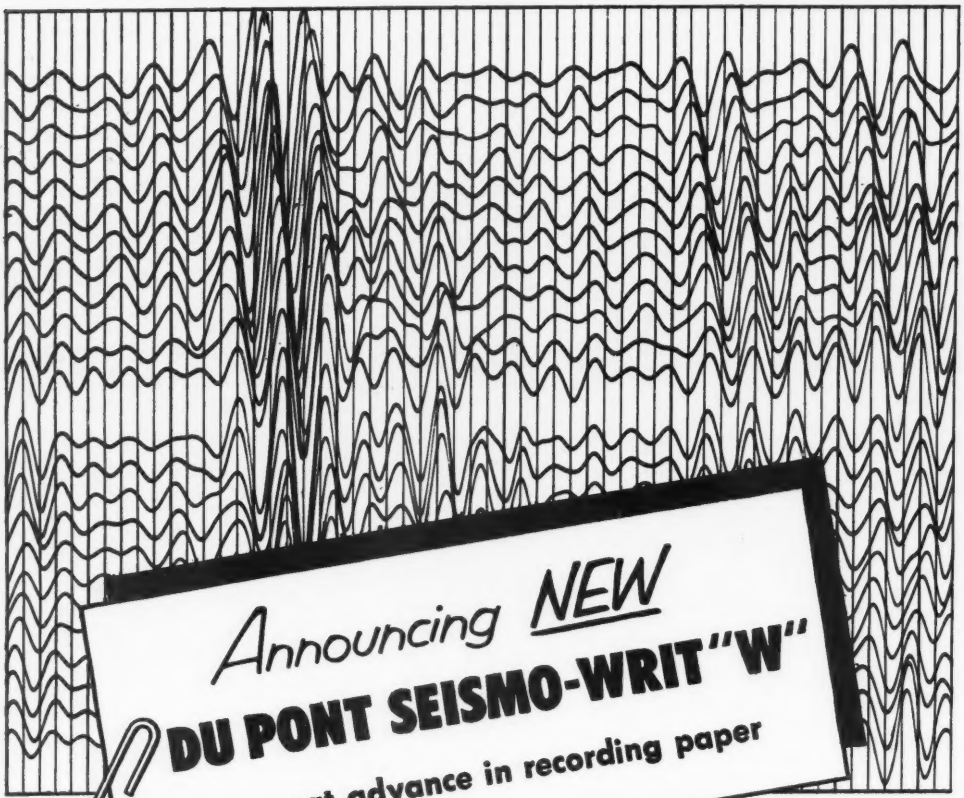

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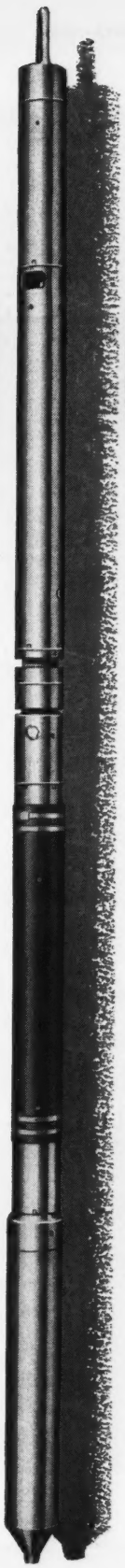

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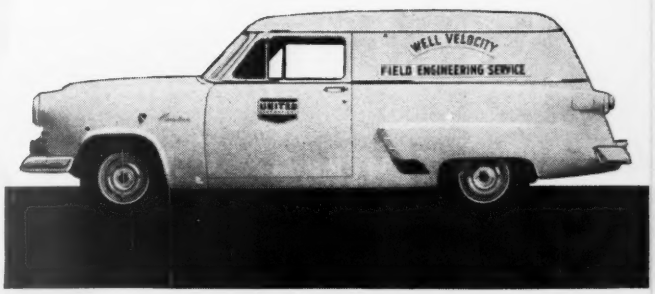

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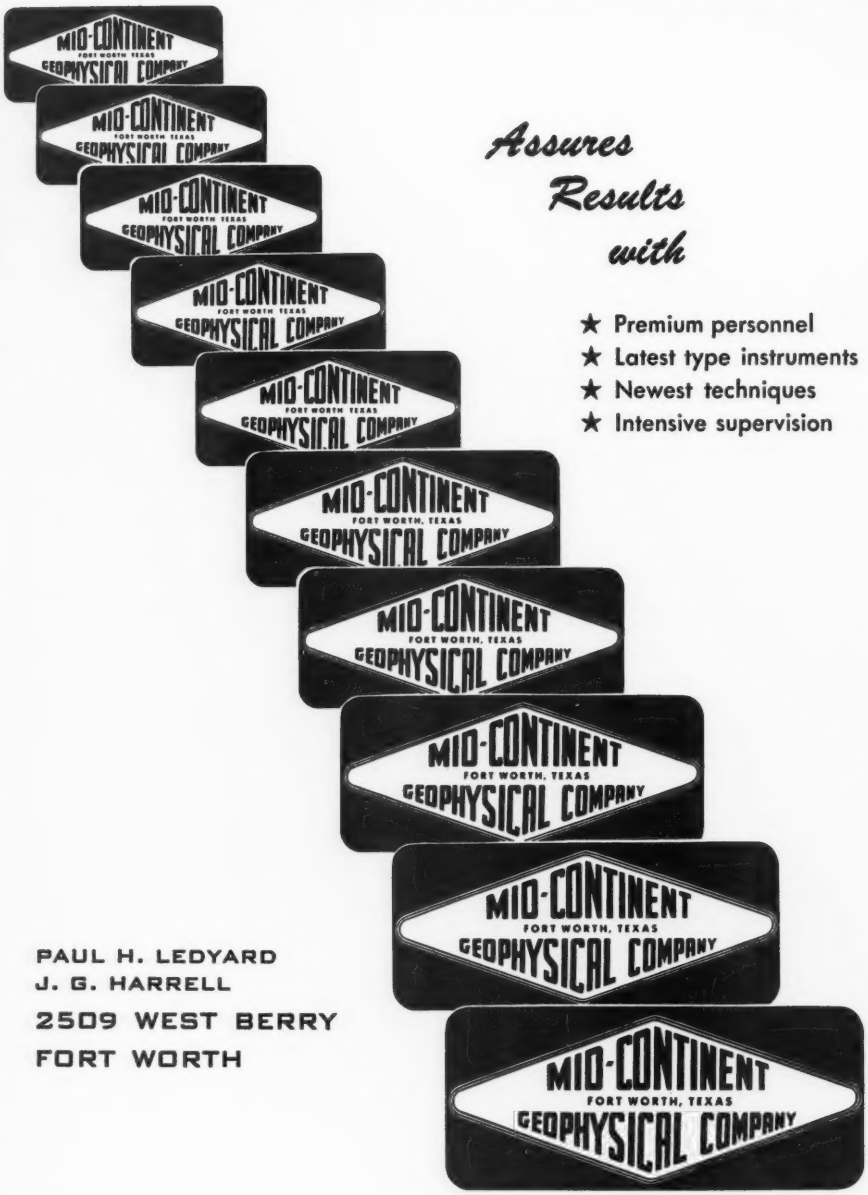

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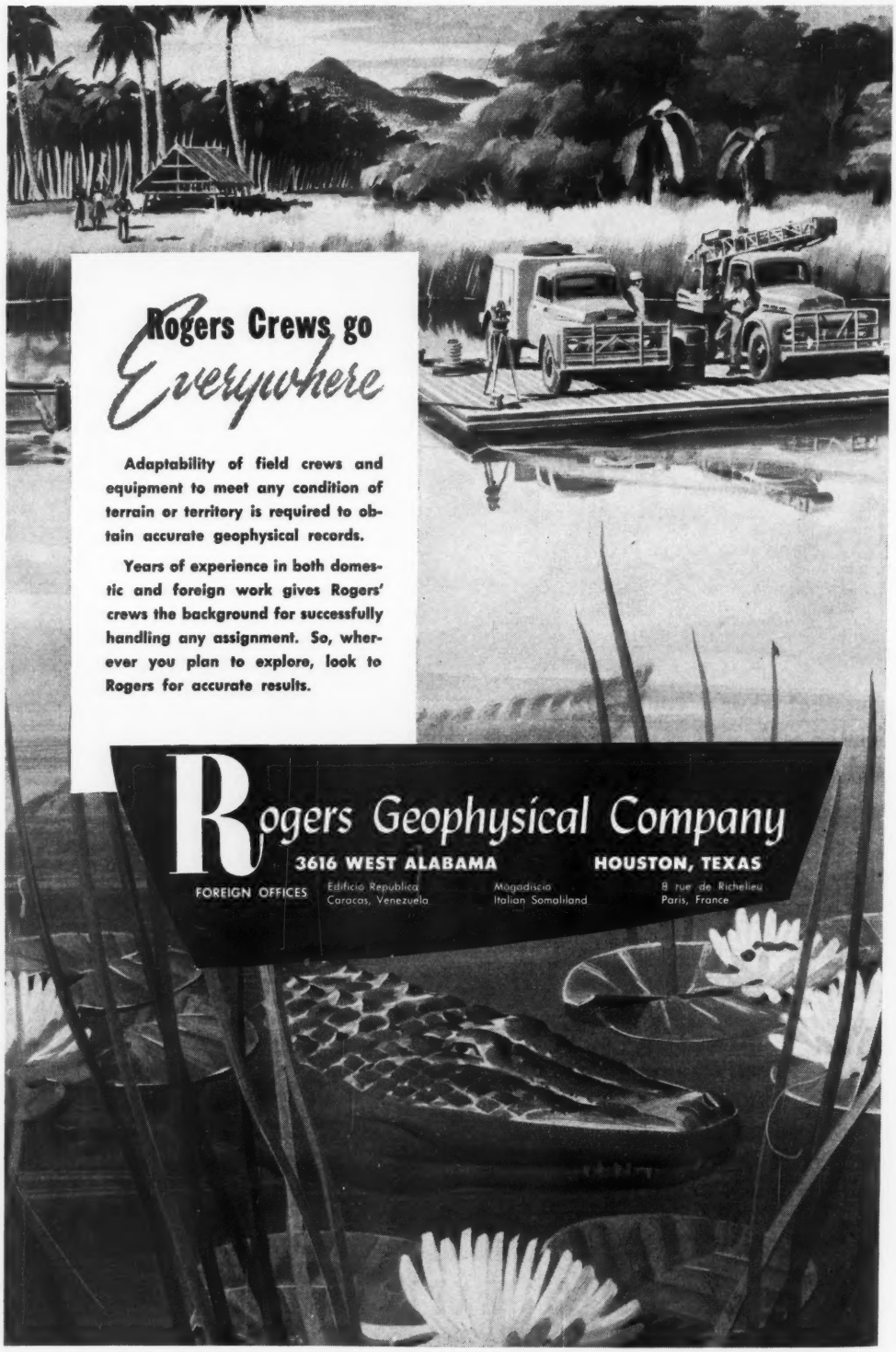
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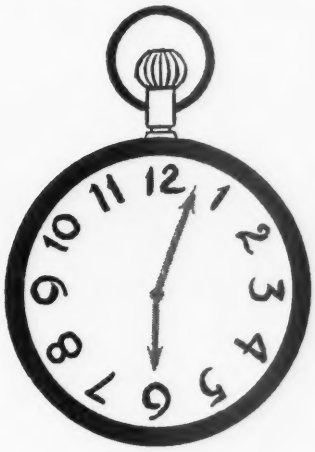

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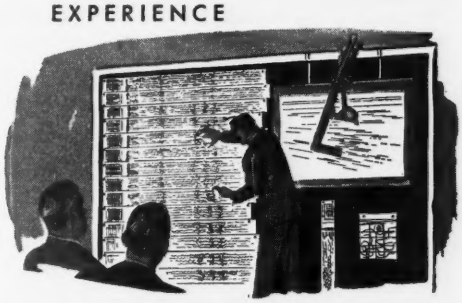

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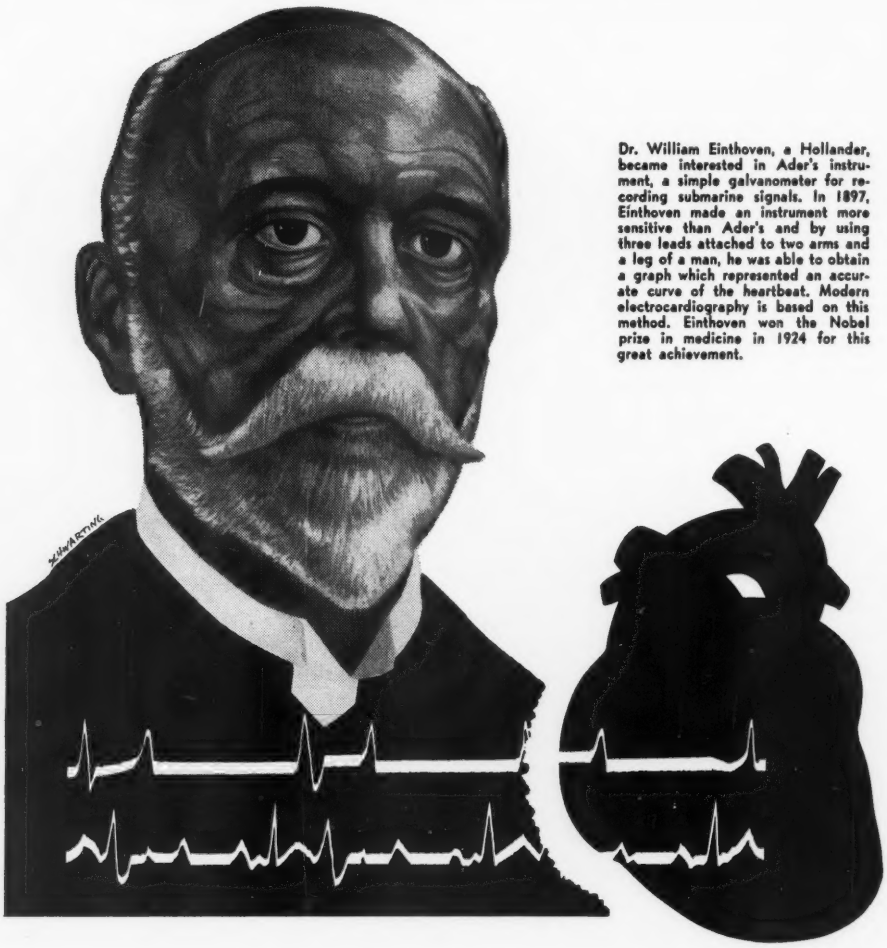

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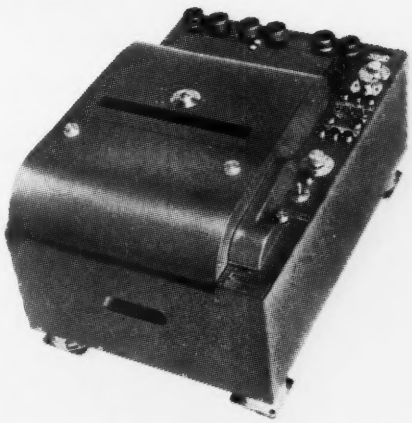

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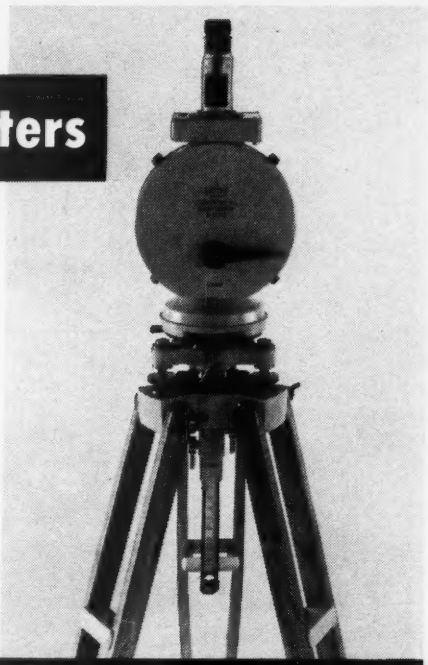

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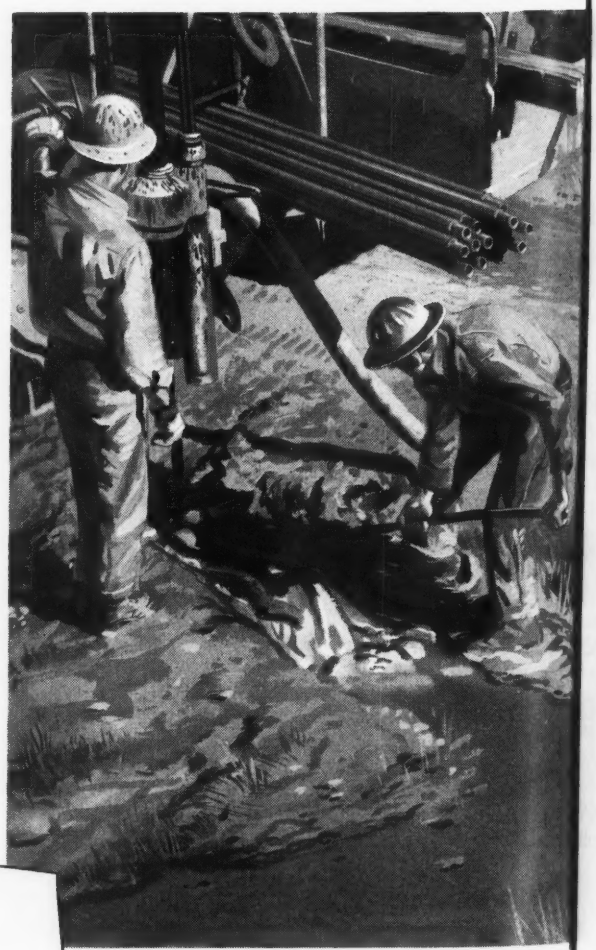

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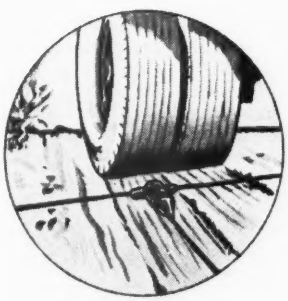

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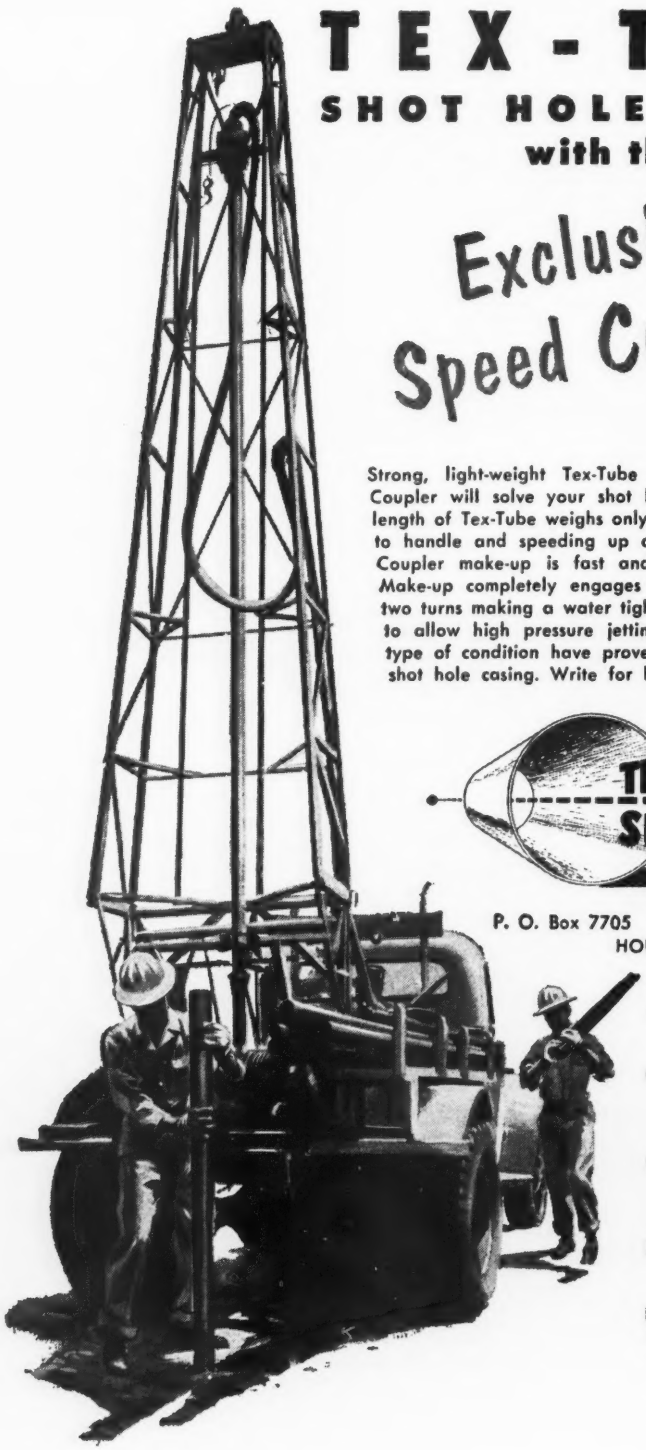

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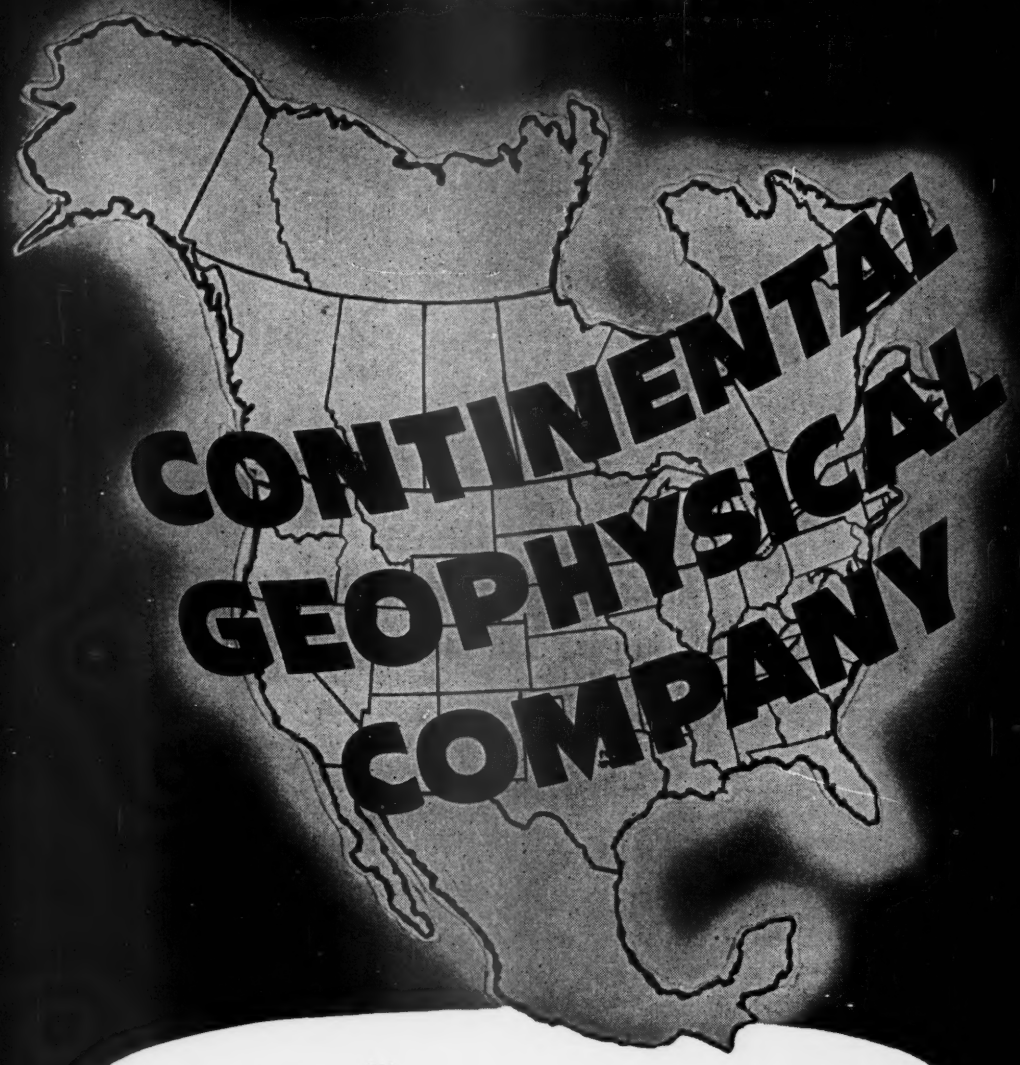

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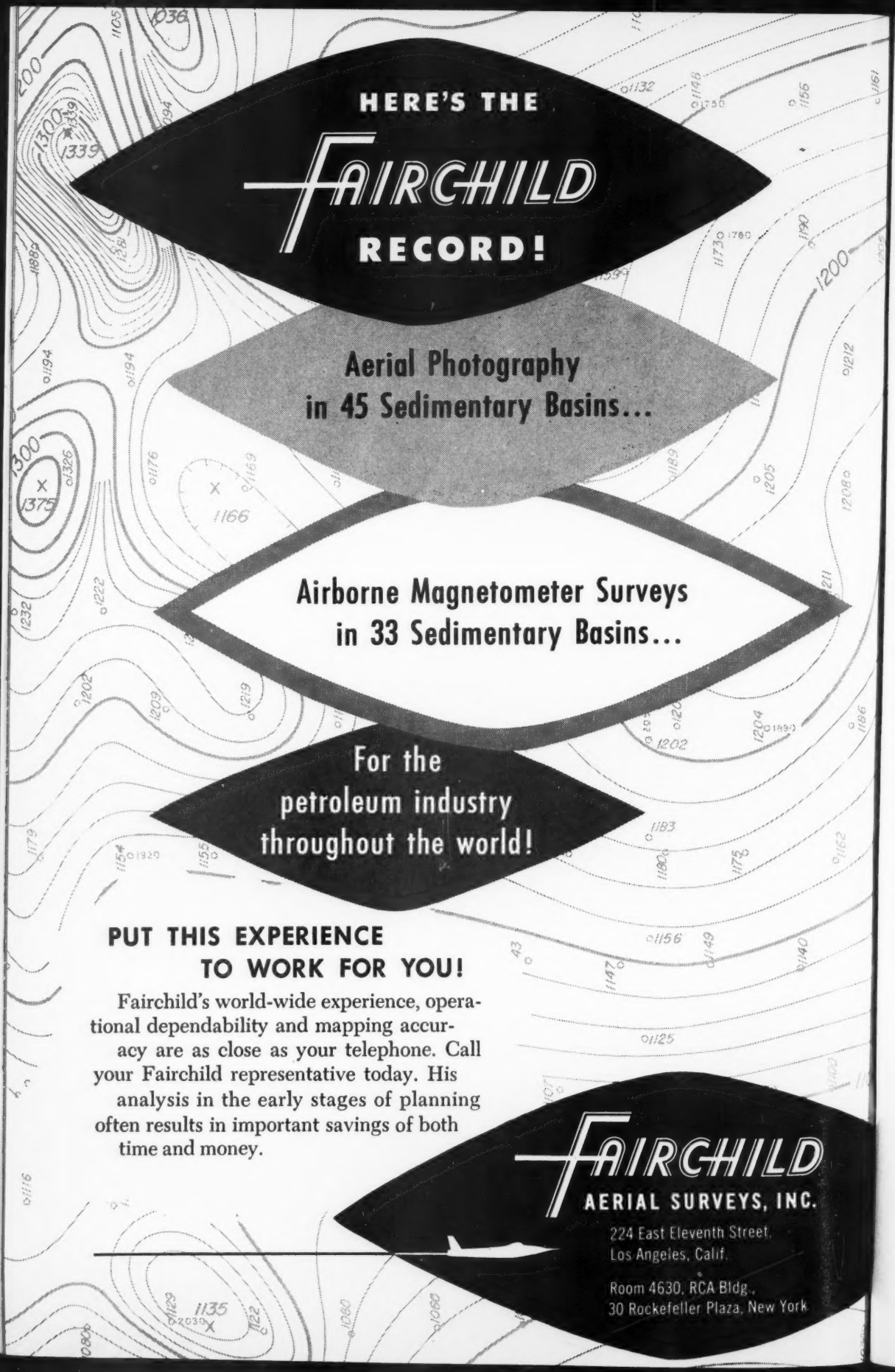

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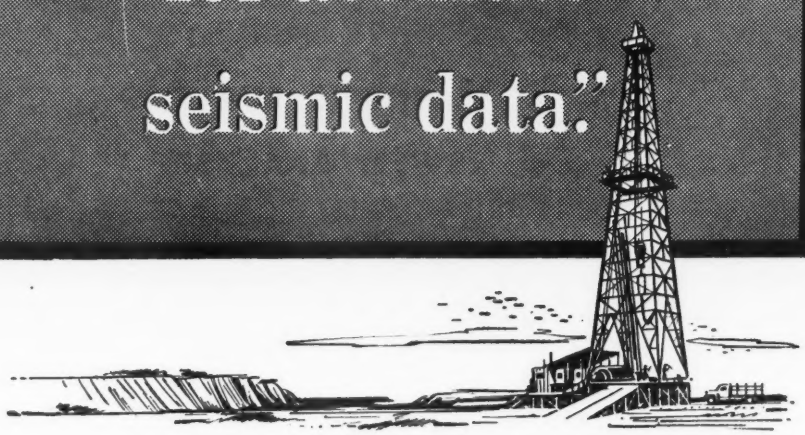

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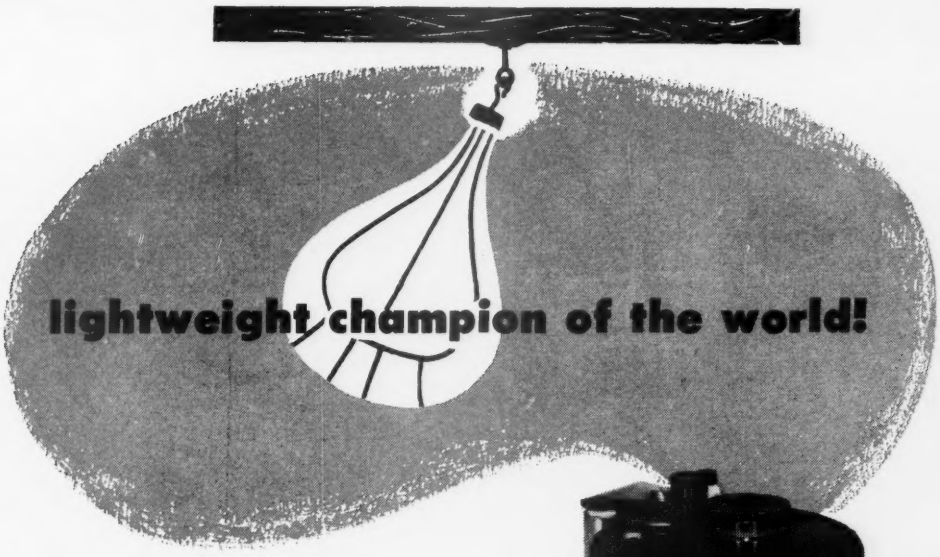

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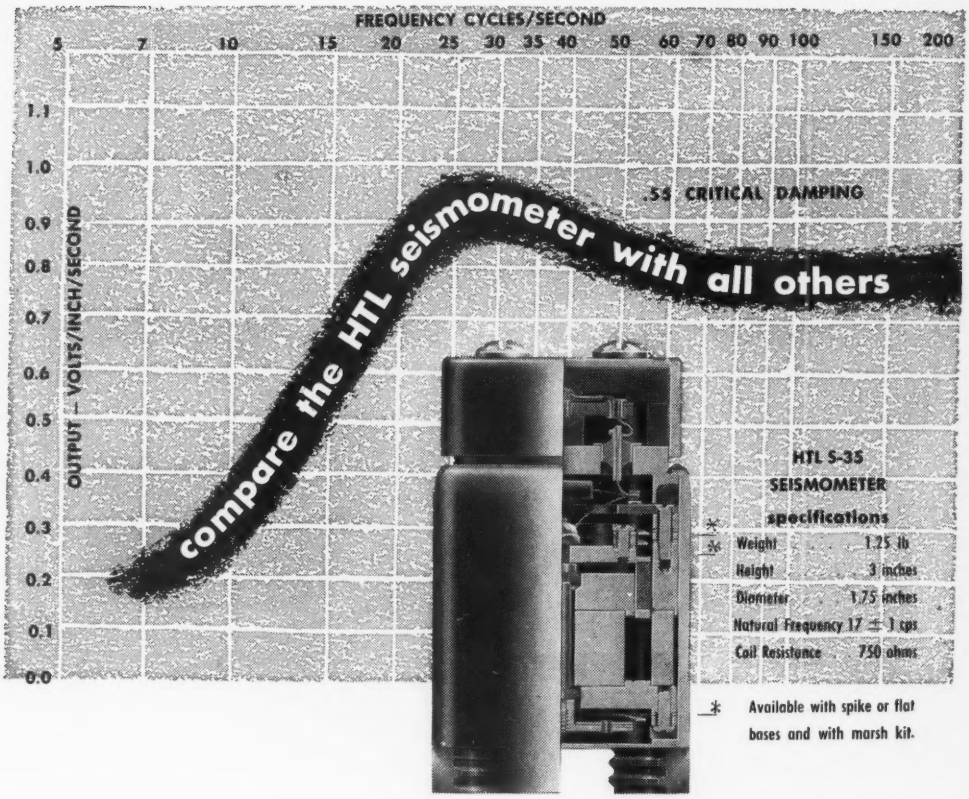
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